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Volcanism in a late Variscan intramontane trough: Carboniferous and Permian volcanic centres of the Intra-Sudetic Basin, SW Poland

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Abstract The Intra-Sudetic Basin represents a late Variscan intramontane trough situated near the NE margin of the Bohemian Massif. The Carboniferous–Permian molasse succession in the northern part of the basin provides evidence of three stages of volcanic activity during: 1) the latest Visean/earliest Tournaisian, 2) the late Westphalian–Stephanian, and 3) the early Permian, the latter corresponding to the climax of volcanism. Rhyodacites, andesites and basaltic andesites were characteristic of the earlier stages (1 and 2), while basaltic trachyandesites, trachyandesites and rhyolites erupted during the later stages (2 and 3). The earliest volcanism occurred near the northern margin of the Intra-Sudetic Basin and the successive Carboniferous and Permian volcanoes shifted SE-wards with time, consistently with the intrabasinal depositional centres. The location of the volcanoes was controlled by NNW–SSE to NW–SE aligned fault zones. The magmas intruded thicker accumulations of sedimentary rocks within intrabasinal troughs, and erupted through thinner sequences outside the troughs. Effusive to extrusive activity created lava-dominated, composite volcanic centres to the north and west. In the eastern part of the basin the most evolved acidic magmas erupted explosively, with the formation of: 1) a maar belt (late Carboniferous) and 2) a major caldera (early Permian), with subsequent emplacement of subvolcanic intrusions in both cases. The volcanic edifices represented intrabasinal elevations subjected to substantial erosion, with the largest supply of volcanogenic debris into the basin following the most voluminous rhyolitc eruptions in Permian times. The caldera was a centre of lacustrine sedimentation.

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INTRODUCTION

The late stages of the Variscan orogeny in Europe were associated with, and followed by, the development of numerous intramontane basins, the deposition of thick molasse sequences, and intense volcanic activity during Carboniferous and Permian times (Lorenz & Nicholls, 1976, 1984; Menard & Molnar, 1988). These Permo-Carboniferous volcanic rocks range from basic to acidic compositions of tholeiitic, calc-alkaline and alkaline affinities and comprise a wide spectrum of pyroclastic deposits, lava flows and shallow level intrusions (e.g. Benek *et al.*, 1996).

The Intra-Sudetic Basin represents one of the largest late Palaeozoic intramontane troughs, situated in the eastern part of the European Variscides at the NE margin of the Bohemian Massif (Fig. 1). The molasse sequence of the basin provides a record of three successive stages of volcanic activity: during the early Carboniferous, the late Carboniferous and the early Permian (e.g. Tasler, 1979; Nemec *et al.*, 1982; Mastalerz & Prouza, 1995). The well constrained geological and depositional history of the basin, together with the significant geochemical and lithological variation of the volcanic rocks, make the Intra-Sudetic Basin an excellent natural laboratory for comprehensive studies of evolution volcanism in a late Variscan intramontane trough.

The molasse succession of the northern part of the Intra-Sudetic Basin spans early Carboniferous–Permian times and hosts the main occurrences of volcanic rocks (Fig. 1). The geology, petrology and geochemistry of these volcanic rocks were extensively discussed in the author's unpublished PhD thesis (Awdankiewicz, 1997 a). This paper deals with the geology of the volcanic rocks, with a particular attention to the following problems:

- the classification, distribution and lithological subdivision of the volcanic rocks,
- the form, structure and emplacement mechanisms of the volcanic rocks,

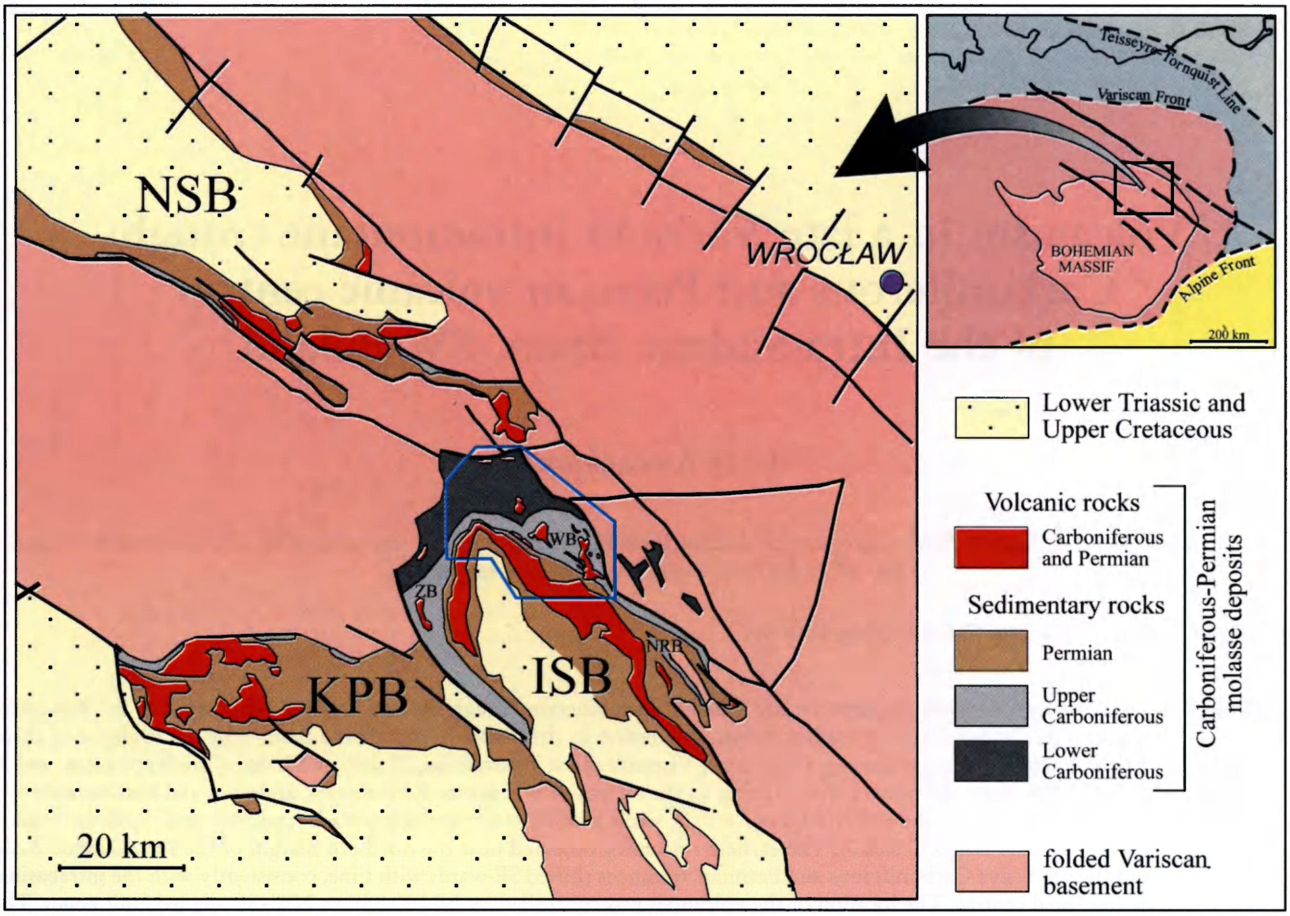

Fig. 1. Distribution of the late Palaeozoic intramontane troughs and molasse deposits in the Sudetes. The study area is marked by the blue box. The inset shows the area of the main map within the Variscan belt. NSB – North-Sudetic Basin, KPB – Krkonose Piedmont Basin, ISB – Intra-Sudetic Basin (WB – Wałbrzych Basin, ZB – Žacleř Basin, NRB – Nowa Ruda Basin).

- the location, type and development of the volcanic centres.

Based on these results, an attempt is made towards the assessment of the main interrelationships between tectonism, sedimentation and volcanism. This paper provides also the basis for a study of the geochemistry and petrogenesis of the volcanic rocks, which will be addressed in a separate publication.

PREVIOUS WORK

THE STRUCTURE AND PALAEOGEOGRAPHIC EVOLUTION OF THE INTRA-SUDETIC BASIN

The Intra-Sudetic Basin (Fig. 1) is c. 60 km long and up to c. 35 km wide, NW–SE trending synclinorial structure, filled with an early Carboniferous to late Permian molasse succession, overlain by early Triassic and late Cretaceous deposits (Tasler, 1979; Nemec *et al.*, 1982; Dziedzic & Teisseyre, 1990; Mastalerz & Prouza, 1995). The molasse succession (Fig. 2) is over 10 km thick, with up to 6.5 km of Lower Carboniferous sediments, up to 2 km of Upper Carboniferous and up to 1.5 km of Lower Permian. However, the distribution of deposits is asymmetric. The Lower Carboniferous deposits attain their greatest thickness in the NW part of the basin. The thickest accumulations of Late Carboniferous deposits occur further SE, within three intrabasinal depositional centres: the Žacler, Wałbrzych and Nowa Ruda Basins. The Permian sequence is thickest in the central and SE parts of the Intra-Sudetic Basin. The basin fill is weakly deformed and the strata in general dip towards the basin axis at moderate to low angles.

The molasse sequence consists of mostly continental siliciclastic deposits arranged into several fining-up megacyclothems, 200-500 m thick (Fig. 2). The volcanic rocks form the most extensive complex, up to nearly 1 km thick, within the Permian deposits. More scattered outcrops of volcanic rocks within the Carboniferous strata are concentrated adjacent to the late Carboniferous depositional centres mentioned above (Fig. 1).

The Intra-Sudetic Basin was initiated as a narrow tectonic graben, but the sedimentation area expanded and the depositional centres moved south-eastwards with time (Wojewoda & Mastalerz, 1989; Dziedzic & Teisseyre, 1990; Bossowski & Ihnatowicz, 1994 a, b; Mastalerz & Prouza, 1995; Mastalerz, 1996 a). Palaeogeographic relationships during latest Carboniferous–early Permian times, at the stage of the maximum extent of the basin, have been compared to the classic Basin and Range province (Wojewoda & Mastalerz, 1989). The evolution of the basin might have been controlled by a major NW-trending strike-slip dislocation zone, the main Intra-Sudetic Fault (Mastalerz, 1996 a).

Numerous geological and sedimentological studies documented the palaeogeographic evolution of the basin throughout the Carboniferous and Permian (e.g. Nemec *et al.*, 1982; Wojewoda & Mastalerz, 1989; Dziedzic & Teisseyre, 1990; Mastalerz & Prouza, 1995, Mastalerz, 1996 a, and references therein). Alluvial fans developed in the marginal parts of the basin and graded towards the basin centre into an axial fluvial belt (early Visean), fluvial-deltaic-marine system (late Visean), delta and alluvial plains (early Namurian), flood-plain and peat-bog environments (Westphalian), lacustrine environments (Stephanian–early Permian), and fluvial plains (Saxonian). The sequence of characteristic lithologies within the succession, e.g. coal seams in the upper Carboniferous, redbeds in the uppermost Carboniferous and Autunian, and caliche horizons in the Saxonian, indicate a gradual climate change from hot and humid during most of the Carboniferous, to hot and arid towards the end of the Permian.

CARBONIFEROUS AND PERMIAN VOLCANISM

The oldest volcanic phase in the Intra-Sudetic Basin is represented by lavas, tuffs and contemporaneous volcanogenic detritus within lowermost Carboniferous near the northern margin of the basin (Teisseyre, 1966, 1970 a, b, 1971; Nowakowski & Teisseyre, 1971). The products of the next, late Carboniferous phase of volcanic activity, are concentrated along the margins of the Wałbrzych Basin. Grocholski (1965, 1966) characterised their geological forms and structures, suggesting close links between tectonic and volcanic processes and their strong impact on sedimentation, including the abundant supply of volcanogenic debris. Nemec (1979, 1981a) further considered that faults within the basement along the margins of the Wałbrzych Basin controlled the volcanic activity and interpreted the volcanic and volcaniclastic rocks in the eastern part of the basin as a linear belt of maars. However, Dziedzic (1966, 1971) considered the Wałbrzych Basin to represent a caldera developed in late Devonian–Permian times.

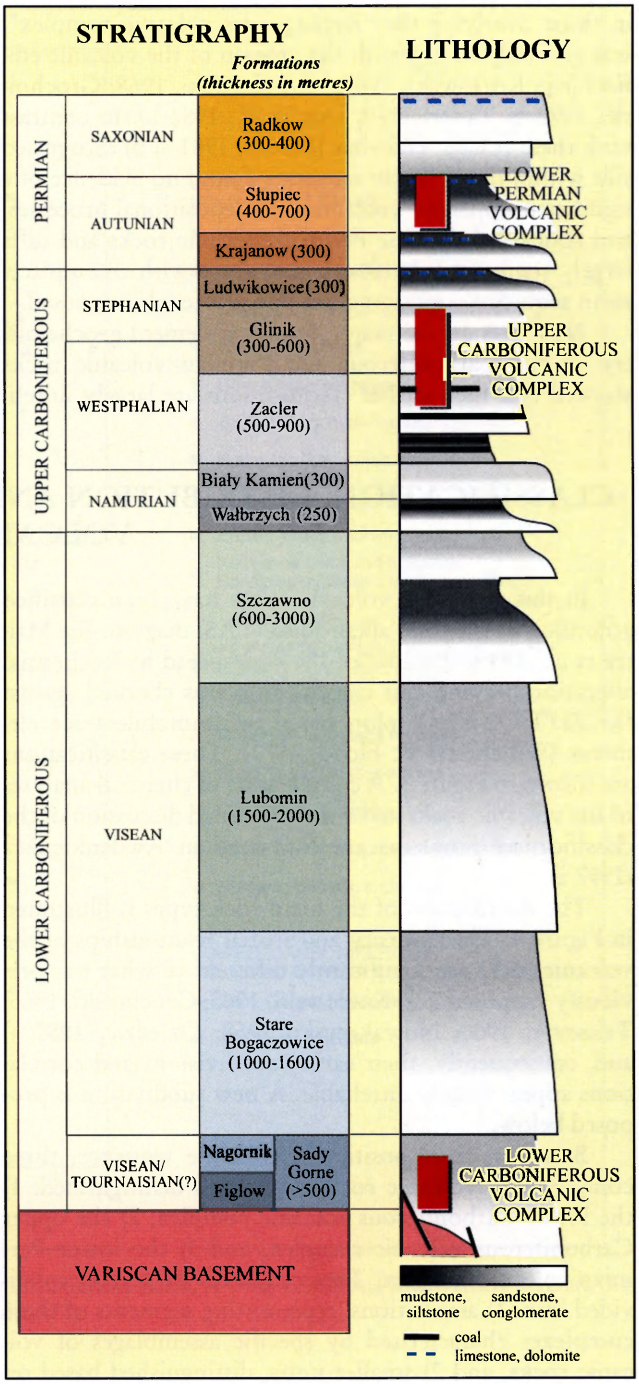

Fig. 2. Stratigraphy and lithology of the Carboniferous–Permian molasse succession of northern part of the Intra-Sudetic Basin (based on Mastalerz & Prouza, 1995).

The most widespread "Rotliegendes volcanic (eruptive) complex" within the Permian deposits reflects the climactic phase of volcanism in the area. This complex was considered by Dziedzic (1958), Kozłowski (1958, 1963) and Nowakowski (1968) to be a sequence of lavas and pyroclastic deposits related to cyclic eruptions from fissure vents and stratovolcanoes, with basic/intermediate compositions at the beginning, and acidic compositions at the end of each cycle. The SE-ward migration of the Permian volcanic centres with time and thickness variations of the lavas related to intrabasinal ridges and troughs were noted by Kozłowski (1963). Wojciechowska and others (1981) and Grocholski (1981) suggested possible locations of the Permian volcanoes in the western and central parts of the Intra-Sudetic Basin and discussed the emplacement style and sequence of the volcanic rocks. The abundance of volcanogenic detritus within the Permian deposits, especially in those overlying the "Rotliegendes volcanic complex", was generally linked with the erosion of the volcanic edifices (e.g. Kozlowski, 1963; Nowakowski, 1968; Grocholski, 1973 b; Tasler, 1979; Don *et al.*, 1981 b). In contrast with these results, Dziedzic (1980 b, 1981 a, b) recognised sills within the Permian sequence, found no evidence of a significant impact of volcanism on depositional processes, and concluded that the Permian volcanic rocks and tuffs largely represent subvolcanic intrusions with an emplacement sequence opposite to the one previously supposed.

New data on the major and trace element geochemistry of the Carboniferous and Permian volcanic rocks showed that their earlier classifications are largely unreliable and that the spatial relationships of the main rock types are significantly different than considered so far (Awdankiewicz, 1994 a, 1997 b). Permian eruptive centres of basic and acidic lavas in the western and central parts of the Intra-Sudetic Basin were described (Awdankiewicz, 1997 c; Awdankiewicz *et al.*, 1998). The eruption of voluminous Permian rhyolitic tuffs was linked with a caldera in the eastern part of the basin (Awdankiewicz, 1998). A strong influence of the rhyolitic volcanism on sedimentation, both through the changes in basin floor morphology (rhyolitic hills to the west, caldera to the east) and abundant supply of volcanic debris, has been suggested (Awdankiewicz, 1998; Awdankiewicz *et al.*, 1998).

CLASSIFICATION, DISTRIBUTION AND LITHOLOGICAL SUBDIVISION OF THE VOLCANIC ROCKS

In this study the volcanic rocks have been classified according to the total alkali-silica (TAS) diagram (Le Maitre *et al.*, 1989). Because of the widespread hydrothermal alteration present, this classification was checked against the Zr/TiO2-Nb/Y plot, based on immobile trace elements (Winchester & Floyd, 1977). These classifications are shown in Figure 3. A complete set of chemical analyses of the volcanic rocks and a more detailed discussion of the classification problems are contained in Awdankiewicz (1997 a).

The distribution of the main rock types is illustrated in Figure 4. The diversity and spatial relationships of the volcanic rocks are significantly different to what was previously supposed (e.g. Kozlowski, 1963; Grocholski, 1965; Teisseyre, 1966; Nowakowski, 1968; Dziedzic, 1980 a) and, consequently, their earlier subdivisions and correlations appear largely unreliable. A new subdivision is proposed below.

Based on their position within the sequence, three complexes of volcanic rocks have been distinguished: 1) the lower Carboniferous volcanic complex, 2) the upper Carboniferous volcanic complex, and 3) the lower Permian volcanic complex. The complexes are further subdivided into: 1) associations, representing segments of these complexes characterised by specific assemblages of volcanic rocks, and 2) smaller units, distinguished based on composition and distribution of volcanic rocks. These subdivisions are illustrated in Figure 5, and the distribution of the units is shown on several maps (Figures 6, 8, 9, 11, 15, 24 and 30).

The lower Carboniferous volcanic complex consists of two units: Sady Górne rhyodacites (SGRd) and Nagórnik andesites (NA). The upper Carboniferous volcanic complex consists of:

- the western Wałbrzych Basin volcanic association, strongly dominated by rhyodacites (Chelmiec rhyodacites, ChRd, and Stary Lesieniec rhyodacites, SLRd), with subordinate rhyolites (Trójgarb rhyolites, TR) and basaltic andesites (Borówno basaltic andesites, BBA), and
- the eastern Walbrzych Basin volcanic association, composed largely of rhyolitic tuffs and rhyolites (Rusinowa-Grzmiąca rhyolites, RGR) with subordinate trachyandesites (Rusinowa-Grzmiąca trachyandesites, RGTa).

The lower Permian volcanic complex consists of three associations:

- the Góry Krucze volcanic association, which is a bimodal assemblage consisting of Kamienna Góra basaltic trachyandesites (KGBTa) and Góry Krucze rhyolites (GKR),
- the Unisław Śląski volcanic association, characterised by the greatest abundance of intermediate rocks (Stożek Wielki trachyandesites, SWTa, Grzędy trachyandesites, GTa) accompanied by basic and acidic lavas (Lesieniec-Sokołowsko basaltic trachyandesites, LSBTa, Dzikowiec rhyolites, DR, Lugowina rhyolites, LgR, and Waligóra rhyolites, WR), and
- the Rybnica Leśna volcanic association (RLVA), which consists of only intermediate and acidic rocks (Bukowiec trachyandesites, BuTa, Gluszyca trachyandesites, GłTa, and Lomnica rhyolites, LR).

The Góry Suche rhyolitic tuffs (GSRT) are distinguished as a separate unit of the lower Permian volcanic complex.

This subdivision is currently considered to be a working scheme that provides a framework for a more detailed geological characterisation of the volcanic rocks, given below.

LOWER CARBONIFEROUS VOLCANIC COMPLEX

SADY GÓRNE RHYODACITES (SGRd)

The Sady Górne rhyodacites are an up to 50 m thick sequence of acidic lavas and tuffs outcropping between the villages of Stare Bogaczowice and Sady Górne, within the Sady Górne Formation (Fig. 6 a). The sequence consists of two horizons of

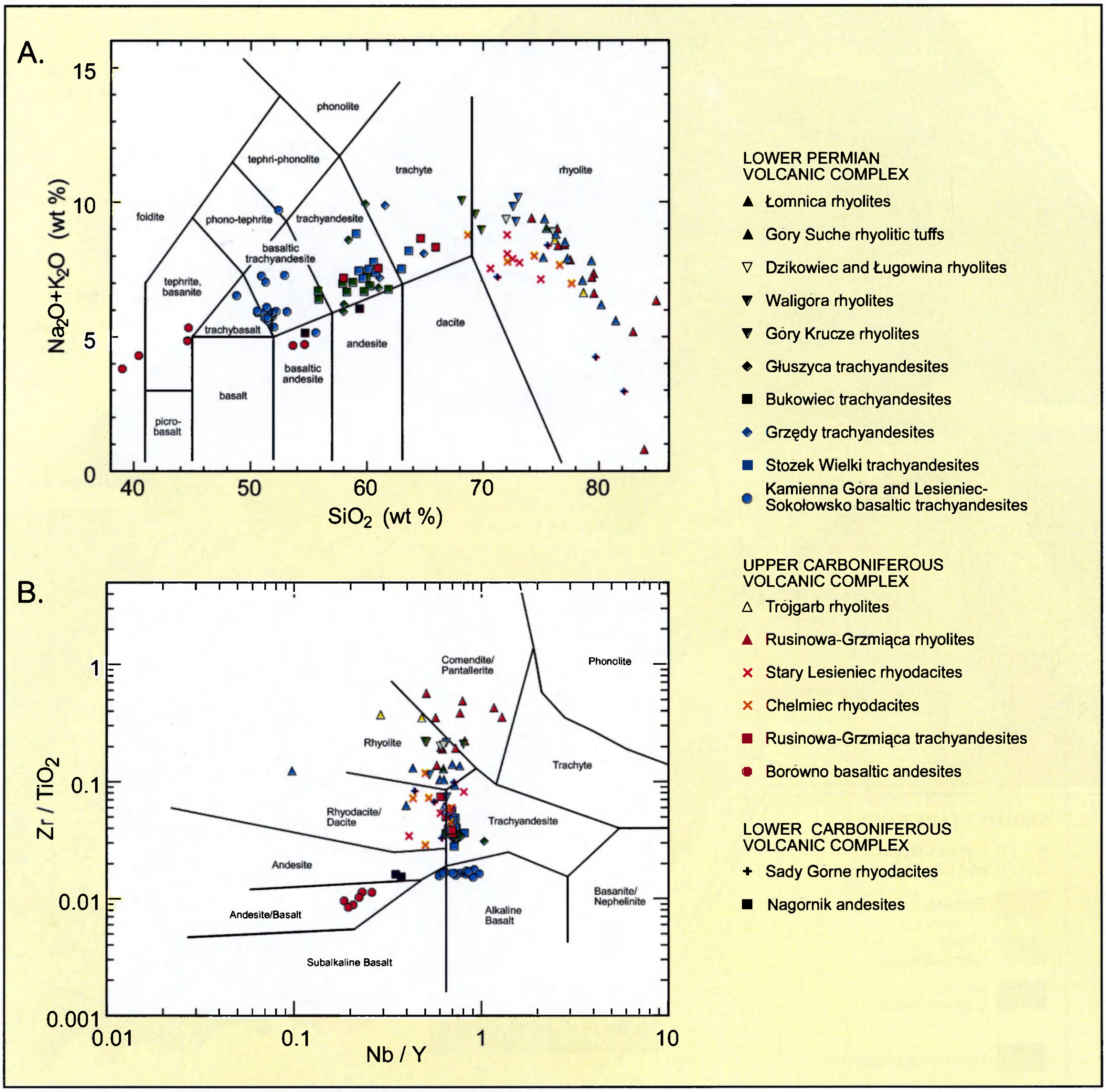

Fig. 3. Classification of the volcanic rocks of the northern part of the Intra-Sudetic Basin. A – the TAS (total alkalis-silica) diagram (Le Maitre *et al.*, 1989). B – the Zr/TiO2-Nb/Y plot (Winchester & Floyd, 1977).

volcanic rocks separated by conglomerates and sandstones. Although Teisseyre (1966) classified the successive lavas as rhyolites (the lower horizon) and trachybasalts and dellenites (the upper horizon), such variation is not confirmed by the trace element geochemistry and petrography (Awdankiewicz, 1997 a). The dominant lithology is a phenocryst-poor rhyodacite (up to 3 % phenocrysts), interlayered with tuffs within the lower horizon, and with phenocryst-rich rhyodacites (10–15 % phenocrysts) in the upper horizon (Fig. 6 b).

The contacts of the rhyodacites of the lower horizon with the surrounding sedimentary rocks (observed in pits, Teisseyre, 1966) are conformable and sharp. The basal part of the lowermost lavas contains numerous xenoliths derived from the underlying conglomerates, and the latter are strongly kaolinitized in a zone a few metres thick below the base of the rhyodacite. The lavas commonly display flow banding and lamination and irregular to platy or blocky joints. Well developed columnar joints are found in the phenocryst-poor lavas of the upper horizon (Fig. 7).

The tuffs of the lower volcanic horizon show indistinct wavy lamination and, possibly, a normal grain-size grading (Teisseyre, 1966). They contain abundant "pisoliths" – ellipsoidal to spherical aggregates, usually 0.5–3.5 cm in diameter, locally with a concentric internal structure (accretionary lapilli ?). Subordinate components of the tuffs are angular lithic clasts (devitrified acid lavas, phyllites and quartzites).

Interpretation. As in Teisseyre (1966) the Stare Bogaczowice rhyodacites are considered to reflect the earliest phase of volcanic activity in the Intra-Sudetic Basin, associated with the basin opening in latest Tournaisian/earliest Visean times. An easterly location for the eruptive centre of the acidic lavas was suggested by Teisseyre (1966, 1970 a) based on the transport directions of the Sady Górne For-

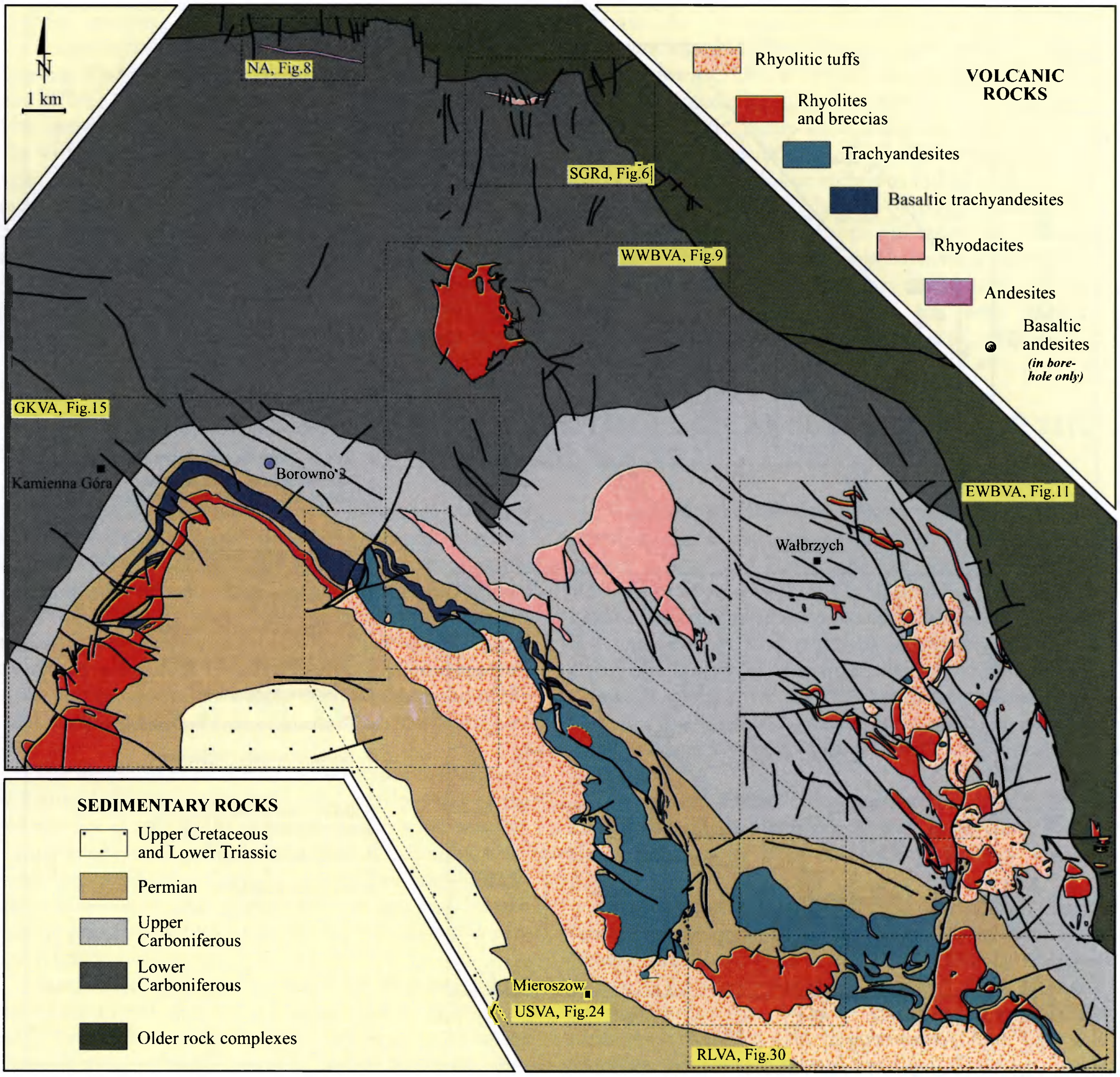

Fig. 4. Generalised geological map of northern part of the Intra-Sudetic Basin and the distribution of the main types of volcanic rocks. Frames (broken lines) indicate volcanic associations shown on more detailed maps.

mation deposits, and on the westward dilution of the contemporaneous volcanogenic debris within these deposits. Indeed, small acidic dykes and necks of post-early Tournaisian age, cutting the Świebodzice Depression deposits east of Stare Bogaczowice (Fig. 6 a) may correspond to the roots of the eroded eruption centre, while the Stare Bogaczowice rhyodacites may represent lava flows accumulated at the foot of the volcano.

The sequence of rhyodacitic lavas and tuffs reflects two main eruption events, separated by a quiescence (and erosion?) period:

1 – the first event, recorded by the lower volcanic horizon, consisted of the extrusion of phenocryst-poor rhyodacitic lava, accompanied by pyroclastic activity with tuff deposition,

2 – the second event, recorded by the upper volcanic horizon, consisted of the extrusion of phenocryst-rich rhyodacites, followed by phenocryst-poor rhyodacites.

The sequence of eruptive products may have reflected the tapping of a stratified magma chamber. During the first event, the upper, phenocryst-poor and gas-rich part of the chamber was tapped, while the second event also tapped the deeper, phenocryst-enriched part of the chamber. The pyroclastic activity during the initial stages of the first event might also have resulted from the interaction of the ascending magma with ground- or surface water.

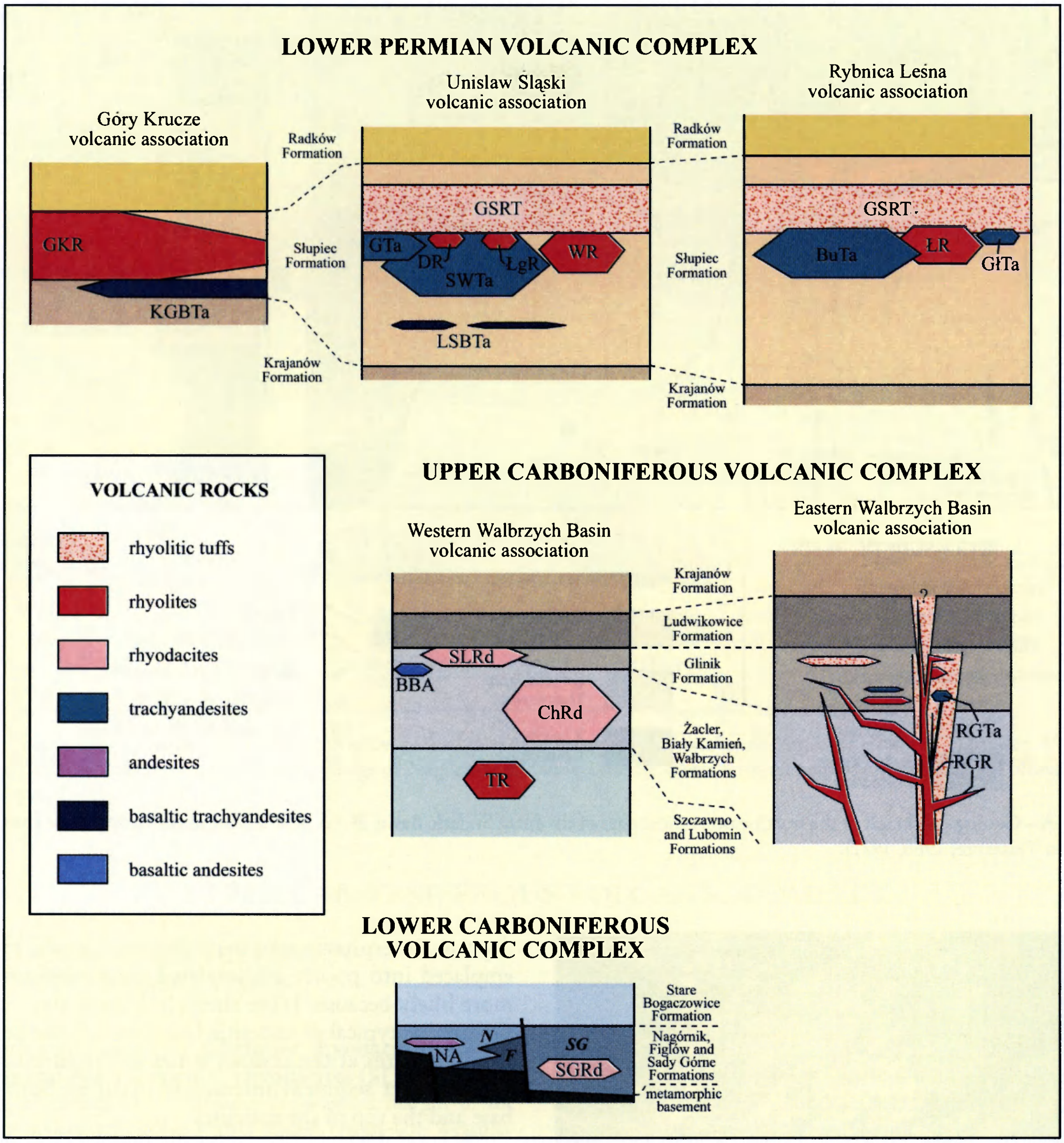

Fig. 5. Subdivision of the volcanic rock complexes of northern part of the Intra-Sudetic Basin. Lower Carboniferous volcanic complex: *SGRd – Sady Górne rhyodacites, NA – Nagórnik andesites.* Upper Carboniferous volcanic complex: western Wałbrzych Basin volcanic association *(BBA – Borówno basaltic andesites ChRd – Chełmiec rhyodacites, SLRd – Stary Łesieniec rhyodacites, TR – Trójgarb rhyolites),* eastern Wałbrzych Basin volcanic association *(RGTa – Rusinowa-Grzmiąca trachyandesites, RGR – Rusinowa-Grzmiąca rhyolites).* Lower Permian volcanic complex: Góry Krucze volcanic association *(KGBTa – Kamienna Góra basaltic trachyandesites, GKR – Góry Krucze rhyolites),* Unisław Śląski volcanic association *(LSBTa – Łesieniec-Sokołowsko basaltic trachyandesites, SWTa – Stożek Wielki trachyandesites, GTa – Grzędy trachyandesites, DR – Dzikowiec rhyolites, ŁgR – Ługowina rhyolites, WR – Waligóra rhyolites),* Rybnica Leśna volcanic association *(BuTa – Bukowiec trachyandesites, GłTa – Głuszyca trachyandesites, ŁR – Łomnica rhyolites),* GSRT – Góry Suche rhyolitic tuffs.

NAGÓRNIK ANDESITES (NA)

The Nagórnik andesites form thin, conformable sheets within the Nagórnik Formation (Fig. 8). The main sheet is up to 3.5 m thick and extends for about 2.5 km, and at locality 2 it is accompanied by two smaller sheets, 0.7 m and 0.5 m thick (Fig. 8 b). The bases of the sheets display load casts with flame-like incursions of the sedimentary substrate and, at the top of the sheets, 'V' shaped cracks are filled with the overlying conglomerates (Nowakowski & Teisseyre, 1971). The country rocks of the andesites show traces of a thermal alteration. The margins of the sheets are characterised by poorly defined flow banding and platy joints, while the interiors of the sheets display variable platy, blocky and columnar joints.

Interpretation. These volcanic rocks were interpreted by Nowakowski and Teisseyre (1971) as lava flows or shallow level sills roughly contemporaneous with their host

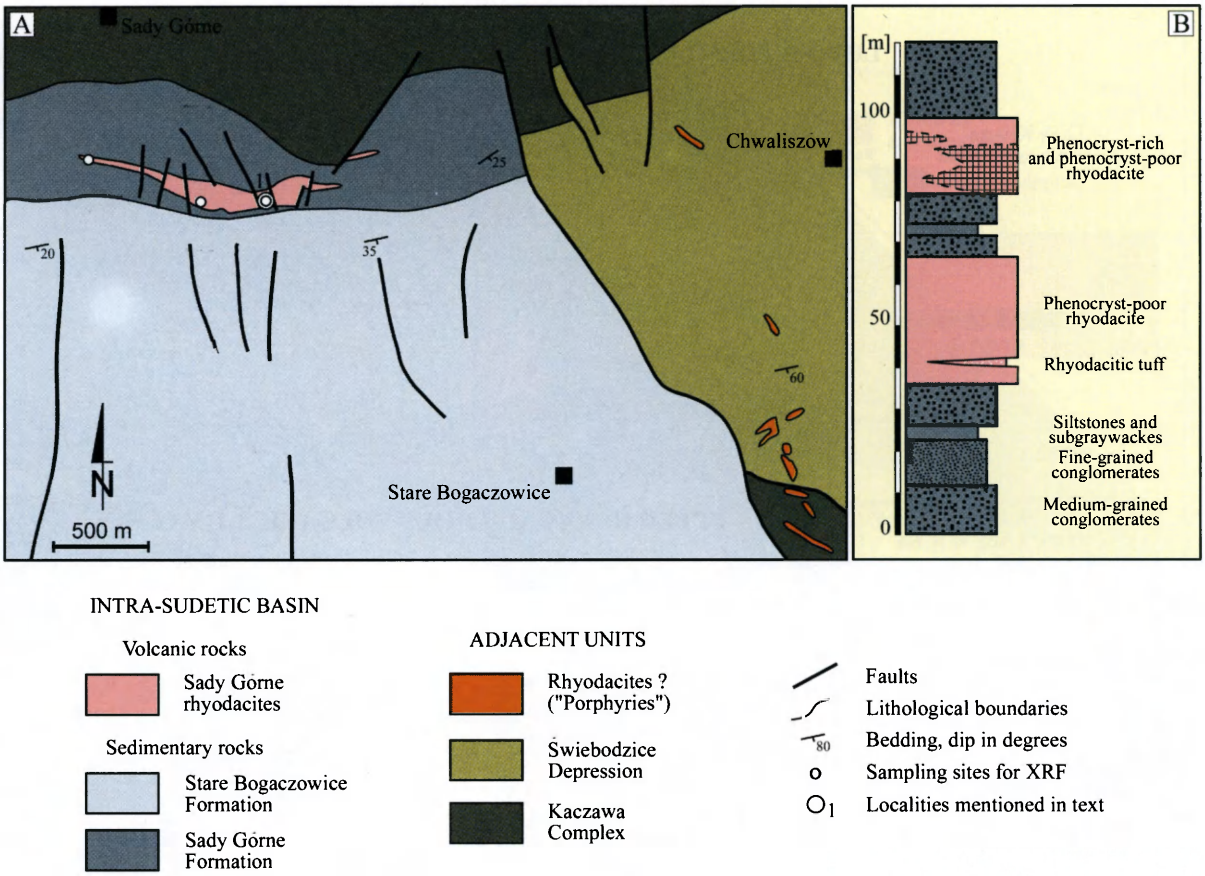

Fig. 6. A – Geological sketch of the north-easternmost part of the Intra-Sudetic Basin. **B** – A detailed log of the Sady Górne rhyodacites (based on Teisseyre, 1966, 1972).

Fig. 7. Sady Górne rhyodacites. The photo shows columnar joints in the central part of lava flow in an abandoned quarry west of the village of Wrony (locality 1, Fig. 6).

deposits. Interpretation of the andesites as small intrusions emplaced into poorly consolidated conglomerates seems more likely because: 1) the sheets lack associated autoclastic breccias typical of andesitic lava flows, 2) the deformation structures at the contact zones of the sheets suggest that lava-wet sediment interaction occurred both at the base and the top of the andesites.

No conclusive evidence for the feeder location of the andesites has been found. Nowakowski and Teisseyre (1971) considered that the eastward thickening of the andesites reflected vent proximity in that direction. However, the thickness variation is not well constrained (only two exposures), and basic-intermediate lava flows and sills commonly thicken away from their vents, towards shallower slopes and sedimentary basin centres (Cas & Wright, 1987; Francis, 1982; Francis & Walker, 1987). Considering the contemporaneous early Carboniferous tectonic activity along the faults at the northern margin of the Intra-Sudetic Basin, a spatial association of the andesitic magma conduit(s) with these faults seems most likely.

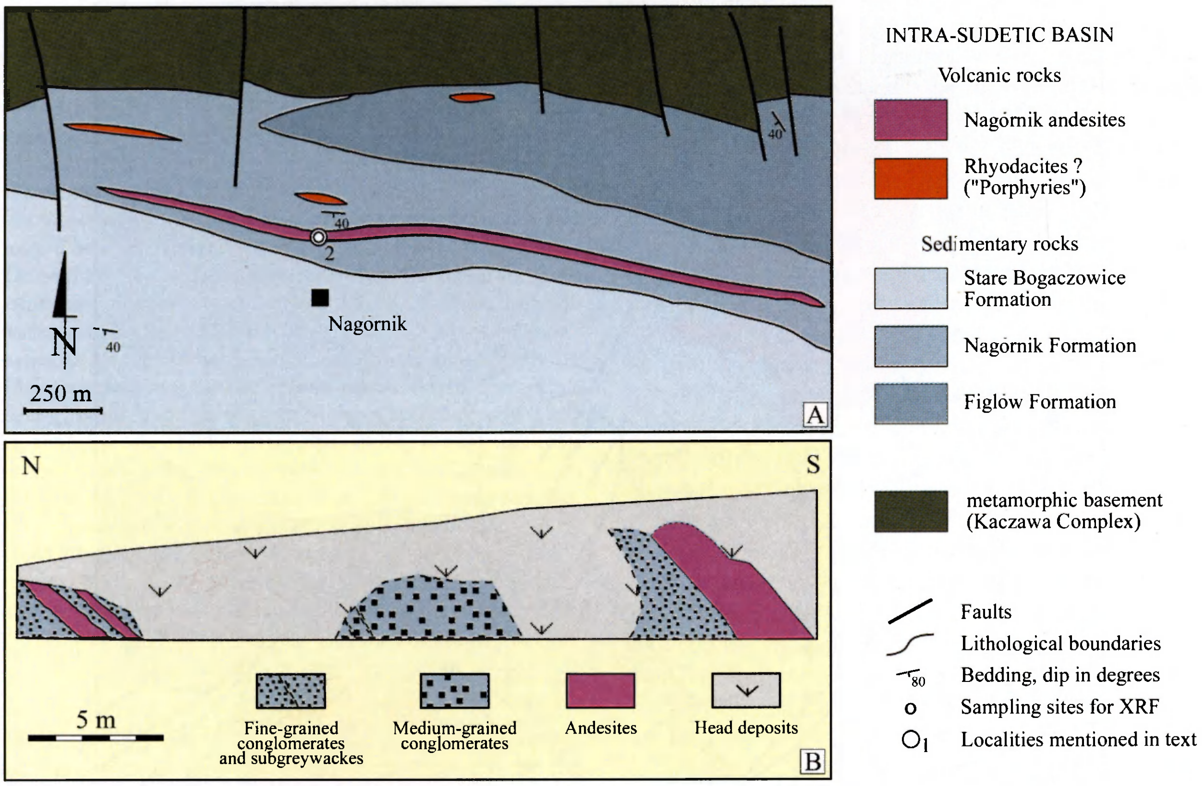

Fig. 8. A – Geological sketch of the northernmost part of the Intra-Sudetic Basin (modified from Cymerman & Mastalerz, 1995). B – Sketch of locality 2 (at the waterfall in the village of Nagórnik) showing andesite sheets within conglomerates (based on Nowakowski & Teisseyre, 1971).

UPPER CARBONIFEROUS VOLCANIC COMPLEX

WESTERN WAŁBRZYCH BASIN VOLCANIC ASSOCIATION

Trójgarb rhyolites (TR), Chełmiec rhyodacites (ChRd) and Stary Lesieniec rhyodacites (SLRd)

These igneous bodies straddle the western margin of the Wałbrzych Basin and occur within folded Visean–late Westphalian deposits, which are unconformably overlain by the late Stephanian Ludwikowice Formation (Fig. 4 and 9). The Trójgarb rhyolites outcrop within Visean deposits, in the hinge of the Jabłów anticline. The western margin of the rhyolites is possibly unconformable and steeply inclined and in the east sandstone and mudstone intercalations within conglomerates semiconformably mantle the rhyolites and define the shallow Modrzewiec syncline. Numerous subsidiary dykes and sills propagate from the main rhyolitic body along its eastern and northern margins.

The Chełmiec rhyodacites form three closely spaced subvolcanic intrusions (Grocholski, 1965; Nemec, 1979, Bossowski & Czerski 1987, 1988): the Chełmiec laccolith, Sobięcin dyke and Mniszek phacolith (Fig. 9). The Chełmiec laccolith is c. 5 km in diameter and asymmetric in shape. Its NW part, which is exposed at the present erosion surface, is over 600 m thick and towards the S and SE the intrusion wedges out and extends for a few km beyond the outcrop. The laccolith is mantled by the Gorce and Sobięcin synclines to the west and north-east, respectively.

The Sobięcin dyke projects SE-wards for nearly 2 km from the edge of the Chełmiec laccolith outcrop. The dyke is subvertical (with a steep dip to the NE ?), c. 300 m thick, and strikes parallel to the Kuźnice Świdnickie dislocation zone to the SW. At its stratigraphically highest SE termination the dyke splits into several smaller sheets, some of which show stair-and-step morphology (Plewa, 1968; Nemec, 1979).

The Mniszek phacolith is situated in the axial zone of the Gorce syncline. The northern part of the intrusion joins the westernmost margin of the Chełmiec laccolith, and the intersection suggests that this join is a south-eastward dipping dyke.

The Stary Lesieniec rhyodacites outcrop east of the Chełmiec laccolith, at the top of the folded Carboniferous sequence hosting the subvolcanic intrusions described above (Fig. 9). The rhyodacites form a sheet-like, conformable body, up c. 200 m thick in the eastern-central part, and wedge out west- and southwards. The south-easternmost part of the rhyodacites occurs within the Glinik Formation (Westphalian/Stephanian). The latter formation is absent further NW-wards, where the rhyodacites are underlain by the topmost deposits of the Zacler Formation (Westphalian B/C), and overlain by the Ludwikowice Formation (late Stephanian). The hiatus at the base of the Ludwikowice Formation spans the uppermost Westphalian and lower Stephanian and it is possibly accompanied by erosional and angular unconformities (Dziedzic, 1961; Grocholski, 1965, 1973 b; Bossowski & Czerski, 1997, 1988).

The rhyodacites of the western Wałbrzych Basin volcanic association are further subdivided into: 1) phenocryst-poor, massive rhyodacites, 2) phenocryst-poor, flow-banded rhyodacites, and 3) phenocryst-rich rhyodacites (Awdankiewicz, 1997 a). The spatial distribution of these lithologies is tentatively shown in Figure 10 (no detailed mapping has been done). The phenocryst-poor massive rhyodacites, and the almost aphyric, massive rhyolites of Trójgarb, are the most widespread. The largest outcrop

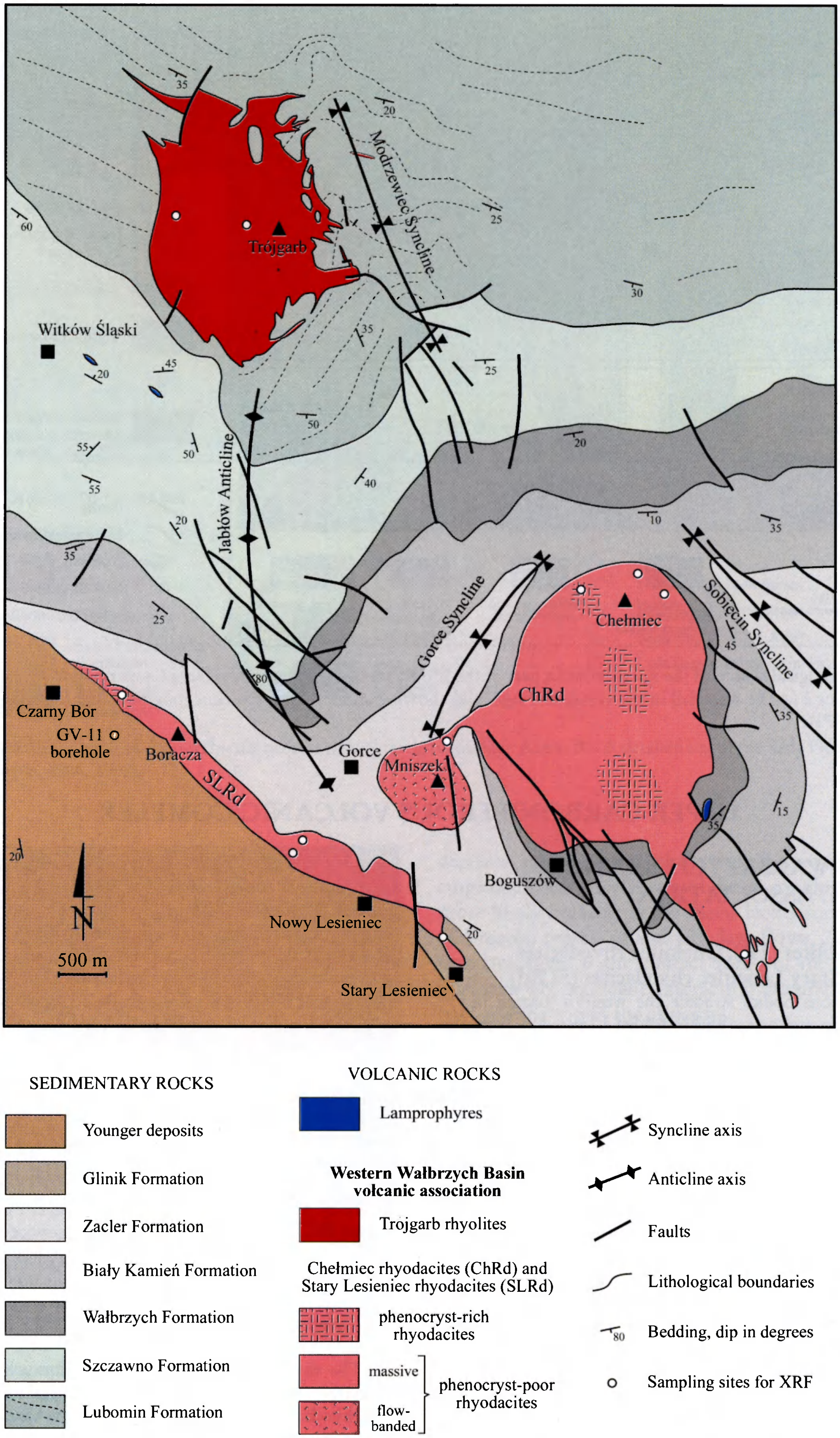

Fig. 9. Geological map of the western Wałbrzych Basin volcanic association (modified from Grocholski, 1973 a; Bossowski & Czerski, 1987; Mastalerz et al., 1995 a).

of the banded, phenocryst-poor rhyodacites is the Mniszek phacolith, but this lithology also occurs in marginal parts of the other igneous bodies. The phenocryst-rich rhyodacites occur at the north-western end of the Stary Lesieniec rhyodacite outcrop and in several localities within the Chełmiec laccolith. In the latter case it is unclear whether they form a continuous, NNW–SSE aligned outcrop, or separate patches.

The structure of the considered igneous bodies is rather monotonous. Their interiors are usually characterised by blocky to irregular or platy joints. Three systems of conical, radial and marginal joints have been distinguished within the Chelmiec laccolith by Grocholski (1965), and near Nowy Lesieniec columnar joints perpendicular to the margins of the rhyodacite body predominate. Flow banding is generally concordant with the margins of the igneous bodies, but flow folds have also been recognised (Grocholski, 1965; Nemec, 1979). Grocholski (1965, p. 44) observed a breccia composed of "porphyry" (rhyodacite) blocks with a red clay matrix in pit(s) at the top of the Stary Lesieniec rhyodacites. The breccia graded downwards into a highly cracked "porphyry", and interdigitated with the overlying sedimentary rocks. Small clastic veins, formed due to the brecciation and fluidisation of sedimentary rocks by volcanic gases and heated pore water adjacent to the Sobięcin dyke were described by Mastalerz and Mastalerz (1988).

Interpretation. As in Grocholski (1965) and Nemec (1979), the volcanic rocks of the western part of the Walbrzych Basin are considered to represent a complex of syntectonic, largely subvolcanic igneous bodies. The geological and stratigraphic relationships described above (transgressive uppermost Stephanian deposits over folded and possibly eroded deposits which are older than upper Westphalian) show that the interrelated tectonic and igneous activity occurred during the late Westphalian–early Stephanian, and was contemporaneous with the deposition of the Glinik Formation. This interpretation is supported by the significant rearrangement of the depositional system of the Walbrzych Basin and adjacent areas at the Westphalian/Stephanian transition (Bossowski & Ihnatowicz, 1994 b) – most probably, the palaeogeographic changes resulted from the interrelated tectonic and igneous activity (see also Grocholski, 1965; Nemec, 1979). The emplacement sequence of the igneous bodies is poorly constrained and in this study they are considered broadly contemporaneous. The detailed model proposed by Nemec (1979) is treated with caution.

The intrusive character of most of the igneous bodies in that area has always been apparent, and the geological forms of Chelmiec laccolith, Mniszek phacolith and Sobięcin dyke are relatively well constrained. The Trójgarb rhyolites and Stary Lesieniec rhyodacites remain more problematic. The rhyolites have commonly been considered as a plug (e.g. Dziedzic & Teisseyre, 1990; Bossowski & Czerski, 1988). In this study, the Trójgarb rhyolites are tentatively reinterpreted as a laccolith gradational in form between the classical dome-shaped conformable intrusion and the partly discordant punched laccolith as defined by Corry (1988). This interpretation is more consistent with the relationships of the rhyolites to their country rocks characterised above, resembling the relationships found adjacent to the Chelmiec laccolith. The problem, however, remains open, as the structure of the intrusion at depth is unknown.

In contrast to the igneous bodies discussed above, the Stary Lesieniec rhyodacites are most probably of extrusive origin (Berg, 1913; Petrascheck, 1938; vide Nemec, 1979; Grocholski, 1965; Nemec, 1979). This is supported by the geological position of the rhyodacites, which suggests that their emplacement and partial erosion took place before the accumulation of the overlying Stephanian deposits (Fig. 9). A precise distinction between intrusive or effusive emplacement mechanisms remains problematic, both due to the possible gradational, endogenous/exogenous form of the rhyodacites, characteristic of many acidic domes (e.g. Howells *et al.*, 1991; Cas & Wright, 1987), and to the poor exposure of the rhyodacites and their country rocks. Based on the lateral width variation of the outcrop of the rhyodacites Nemec (1979) suggested that they form a few closely spaced domes and flows. This interpretation seems unsupported – it is more probable that the rhyodacites form a single sheet of a relatively high thickness/length ratio typical of acidic, viscous lavas, and that the variable outcrop width results rather from intersection.

The feeders of the acidic magmas in the study area were most probably NW–SE to NNW–SSE trending dykes, subparallel to the Jabłów anticline, controlled by a fault zone within the basement along the western margin of the Walbrzych Basin (Grocholski, 1965; Nemec, 1979). The Mniszek phacolith was probably sourced in a NE–SW trending dyke, related to a local fold of similar axis strike, the Gorce syncline.

A correlation has been found between the lateral thickness variation of the Carboniferous deposits and the distribution and geological forms of the component igneous bodies of the western Walbrzych Basin volcanic association. West and south-westwards, with the thinning of the sedimentary sequence, the igneous bodies are found at successively shallower (younger) stratigraphic levels and grade from subvolcanic intrusions (Trójgarb, Chelmiec, Mniszek) towards extrusions/lava flows (Stary Lesieniec). This suggests that the level and style of emplacement of the rising acidic magmas were controlled by the thickness of the sedimentary sequence which they encountered on their way up: the magma intruded the thickest sequence, and extruded through the thinnest sequence. These relationships are similar to those found between basic sills and sedimentary basins in Scotland and northern England (Francis, 1982; Francis & Walker, 1987; Walker & Francis, 1987) and reflect the influence of density gradients on magma behaviour during its buoyancy-driven rise towards the surface – thick accumulations of young, low density sediments form barriers that trap magmas as subvolcanic intrusions, while thinner sedimentary sequences allow magmas to reach the Earth's surface.

The lithological diversity of the rhyodacites of the western Walbrzych basin volcanic association, with phenocryst-rich and phenocryst-poor types, possibly results from inhomogenity within the chamber(s) from which the magmas originated. The phenocryst-rich rhyodacites could have been derived from a lower (marginal ?) part of the chamber(s), with a high phenocryst/melt ratio, while the phenocryst-poor lithology reflects the tapping of up-

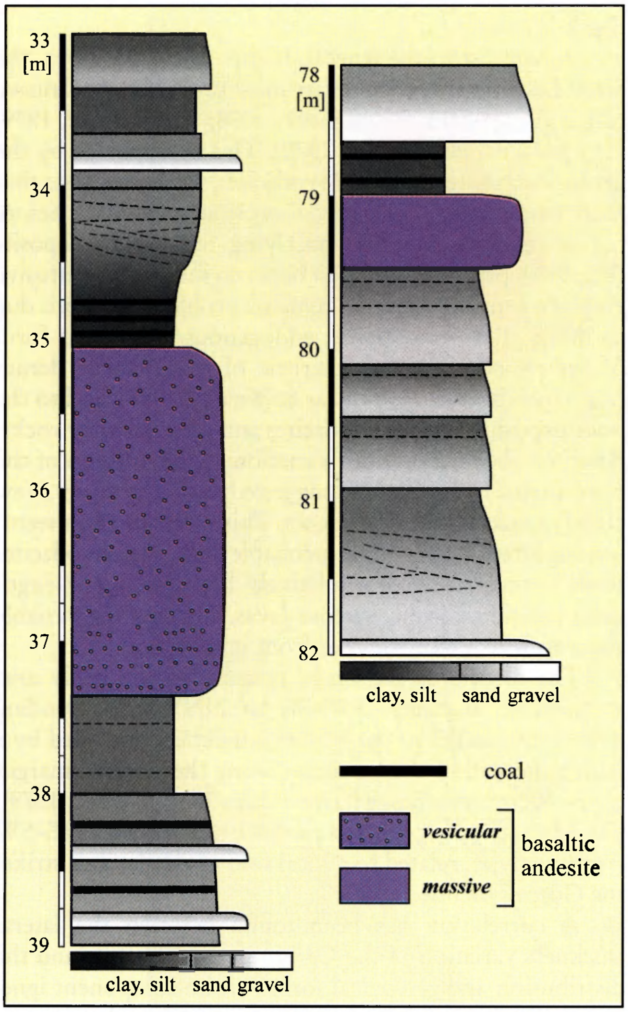

Fig. 10. Schematic logs of the Žacleř Formation deposits hosting the Borówno basaltic andesites (the Borówno-2 bore-hole, intervals 33-39 m and 78-82 m).

per (central ?) part of the chamber, with by a low crystal/melt ratio.

Borówno Basaltic andesites (BBA)

The Borówno basaltic andesites comprise three thin sheets encountered in the uppermost part of the Zacler Formation in the Borówno 2 bore-hole, a few km west of the Walbrzych Basin (Awdankiewicz, 1994 b). The sheets are conformable, c. 3 m, 0.6 m and over 4 m thick, at depths of 35–38 m, 79–79.6 m and 98–102 m, respectively. They are set within sandstones and mudstones with thin coal laminae and conglomerate intercalations (Fig. 10).

The contacts of the basaltic andesites with the sedimentary rocks are sharp. The volcanic rocks show weak lithological variation. No brecciation or thermal joints were observed. The thinnest basaltic andesite sheet is massive and its basal part shows the highest phenocrysts content – c. 10 %, compared with c. 2–4 % typical of the other sheets. The medium thick sheet is amygdaloidal, with thin massive bands near its base. Vesicles, up to 15 mm in diameter, are relatively sparsely distributed (c. 5 % by volume). The thickest sheet is characterised by a massive lower part grading upwards into weakly amygdaloidal top, with small (typically less than 3 mm) and rare (c. 2 %) vesicles.

Interpretation. Although the interpretation of the basaltic andesite sheets as lava flows cannot be definitely excluded, it seems more likely that they represent shallow level sills. The position of the sheets within the sequence, within mudstone and coal beds, is characteristic of many sills which are preferentially emplaced into finer grained horizons (Williams & McBirney, 1979, p. 62). The shallow intrusion level of the basaltic andesites is inferred from their petrographic characteristics, in particular their vesicular and, originally, hypocrystalline textures (Awdankiewicz, 1997 a), indicative of low confining pressure and rapid cooling. Based on this evidence, the Borówno basaltic andesites are considered broadly contemporaneous with, or slightly younger than, their host deposits, i.e. the upper part of the Żacler Formation.

Because of limited data (from one borehole only), the lateral extent and feeder(s) location of the basaltic andesites cannot be easily determined. However, considering the geological position and low thickness of the sheets, together with the lack of reported occurrences of similar rocks in mines and bore holes in this area, a location of the feeders within a few km east of the Borówno 2 bore hole seems likely.

EASTERN WAŁBRZYCH BASIN VOŁCANIC ASSOCIATION

Rusinowa-Grzmiąca rhyolites (RGR)

The main outcrop of the considered rocks is a submeridianal belt known as the Rusinowa-Grzmiąca belt (Fig. 11). It is c. 7 km long, 0.5–2 km wide and strikes obliquely to the SW-wardly dipping Upper Carbonifeorus fill of the Wałbrzych Basin, subparallel to its eastern margin. The belt mainly consists of volcaniclastic rocks, with less widespread rhyolites and minor trachyandesites (the Rusinowa-Grzmiąca trachyandesites). The rhyolites are also abundant within the Carboniferous deposits adjacent to the Rusinowa-Grzmiąca belt, and locally cut gneisses of the Góry Sowie block to the east.

The Rusinowa-Grzmiąca belt consists of several closely spaced or coalescing domains, oval to irregular in shape, commonly less than 1 km in their largest dimension, and cut by NW-SE to N-S trending faults. The domains cut across lithological and lithostratigraphic boundaries within the host sedimentary sequence and no interdigitation of the volcaniclastic rocks and their country rocks has been observed. The intersection shows that the boundaries of the volcaniclastic rocks with their country rocks are discordant, subvertical to inwardly inclined. In the southernmost part of the Rusinowa-Grzmiąca belt a complex outcrop pattern is found (Fig. 11) and the position of the volcaniclastic rocks relative to the lowermost Permian deposits is unclear.

The volcaniclastic rocks form bedded sequences characterised by variable dips, in general steeper than observed in adjacent Carboniferous deposits, and there is evidence of centroclinal dips in places (Krawczyńska-Grocholska & Grocholski, 1958; Grocholski, 1965; Nemec, 1979, 1981a). According to Nemec (1979, 1981a) these rocks are mainly pyroclastic deposits (tuffs and lapilli tuffs) of surge, flow and air fall origin, related to phreatic eruptions (Fig. 12). The accidental lithic components of the volcaniclastic rocks compare well with pebbles within the Żacler Formation, within which most of the volcaniclastic rocks outcrop (Nemec, 1979, 1981a). However, at locality 4 the pyroclastic

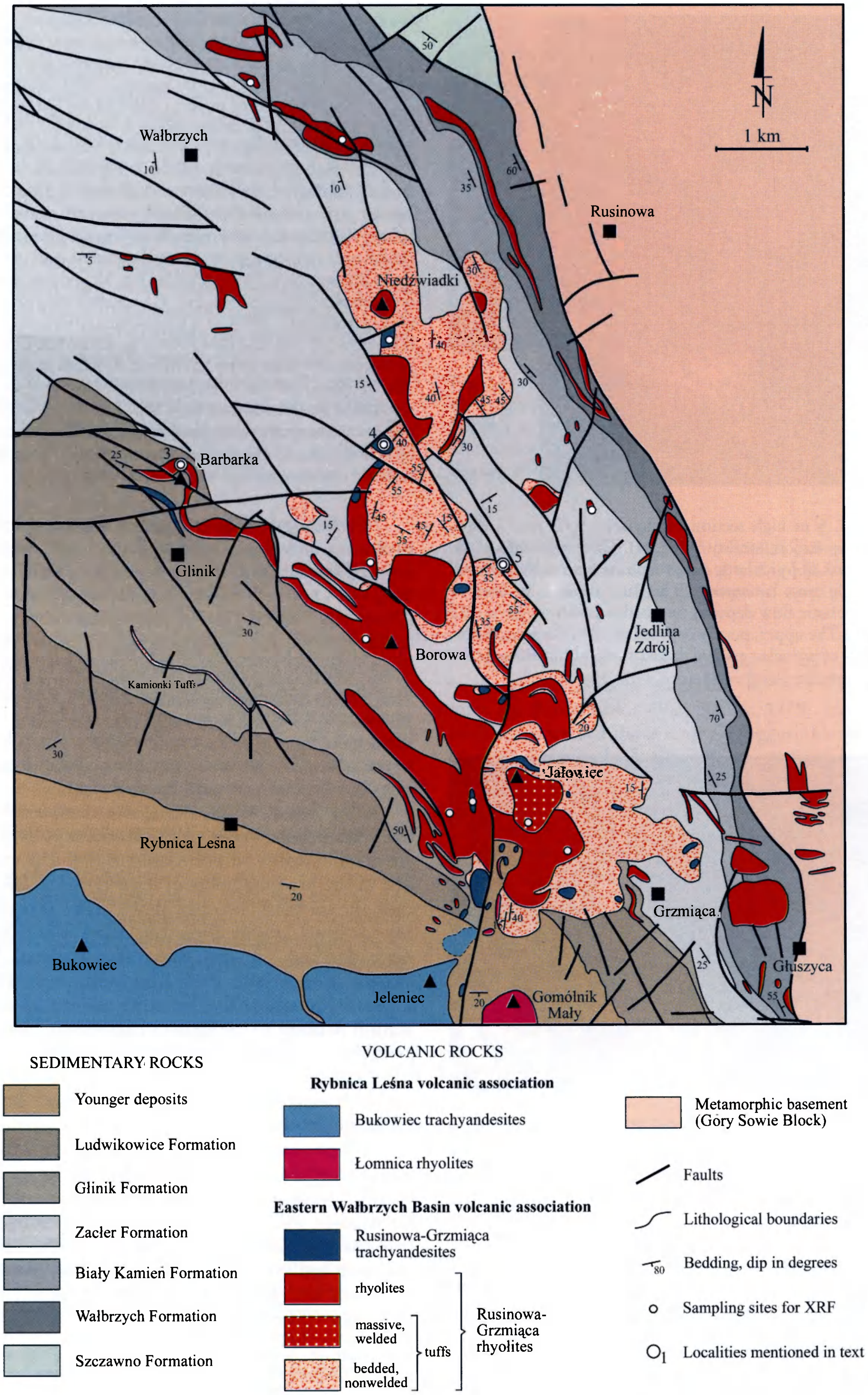

Fig. 11. Geological map of the eastern Wałbrzych Basin volcanic association (modified from Haydukiewicz et al., 1984; Bossowski et al., 1994).

Fig. 12. A c. 5 m high section of rhyolitic tuffs near Jedlina Górna railway station (locality 5, Fig. 11). The lower third of the section consists of pyroclastic surge deposits with subhorizontal and low angle cross lamination. They are overlain by massive beds of pyroclastic flow deposits interbedded with thin layers of fall-out tuffs. The upper, poorly exposed third of the section possibly consists of pyroclastic surge deposits resembling those at the base (interpretation based on Nemec, 1981, Fig. 4).

Fig. 13. Rusinowa-Grzmiąca rhyolites. A flow fold in the lower part of a rhyolitic sheet in an abandoned quarry on Barbarka hill (locality 3, Figure 11).

rocks overlie red-coloured mudstones with discontinuous sandstone and conglomerate beds, disrupted by a trachyandesite intrusion found below (Fig. 14). The red clastics which underlie the tuffs are distinct from the Żacler Formation deposits (typically, grey coloured sandstones and conglomerates) and rather resemble the overlying Glinik Formation. The latter formation locally hosts up to 40 m thick rhyolitic tuff intercalations, known as the Kamionki Tuffs (Grocholski, 1965; Bossowski *et al.*, 1994). Their main outcrop, c. 2 km long, is situated west of the Rusinowa–Grzmiąca belt (Fig. 11), and a smaller one, only c. 300 m long, lies south-east of the belt, near the village of Głuszyca.

The rhyolites of the considered unit form intrusive sheets and plugs and some of them grade upwards into funnel- and dome-like forms (Plewa, 1968; Nemec, 1979). Individual sheets are up to several tens of meters thick and the longest extend for nearly 3 km. Most of them display a complex, "stair and step" morphology, in a combination of dykes, inclined sheets and sills. The sills were generally emplaced along contacts between contrasting lithologies, often those of coal seams and mudstones with coarser grained clastic rocks. The rhyolites are massive to vesicular and flow-banded, with variable polygonal joints and sharp to gradational contacts with the sedimentary and volcaniclastic rocks (Plewa, 1968; Nemec, 1979). The 35 m thick rhyolite sheet on Barbarka hill (locality 3, Fig. 11), variably interpreted as a lava flow (Grocholski, 1965) or a sill (Nemec, 1979), shows well defined flow banding and flow folds (Fig. 13) and carries sandy conglomerate xenoliths up to 1 m in size. A 500 m in diameter "rhyolite" outcrop on the SE slopes of Jałowiec hill in the southern part of the Rusinowa–Grzmiąca belt (Fig. 11) has now been recognised as a strongly welded tuff with a typical eutaxitic structure (Awdankiewicz, 1997 a). The outcrop pattern suggests that the tuffs are intrusive and fill a subvertical plug.

Interpretation. The geological position and age of the Rusinowa–Grzmiąca rhyolites have been variably interpreted. Nemec (1979, 1981a) argued that the rhyolitic tuffs of the Rusinowa–Grzmiąca belt occur as lensoidal masses, interbedded within, and contemporaneous with, their country rocks, and consequently that: 1) the volcanic activity occurred during early Westphalian to early Stephanian times, and 2) the volcanic centres migrated southwards during that time. In contrast, Grocholski (1965) and Bossowski *et al.* (1994) considered that the volcaniclastic rocks infilled discordant, funnel-like volcanic conduits of late Carboniferous or early Permian age.

As in Nemec (1979, 1981a) it is considered here that the volcaniclastic rocks of the Rusinowa–Grzmiąca belt are predominantly of pyroclastic origin, and were deposited in the proximal parts of maar-type volcanoes. However, the evidence described above shows that these rocks are now found inside discordant, pipe- to funnel-like volcanic conduits, or diatremes, as considered by other authors (Grocholski, 1965; Bossowski *et al.*, 1994). Furthermore, in one of the diatremes within the Żacler Formation (locality 4) the tuffs overlie red-coloured deposits possibly equivalent to the Glinik Formation. This, and the steep and centroclinal dips of the tuffs point to a significant subsidence of the volcaniclastic and sedimentary rocks within the diatremes, possibly for several hundred metres (up to above 1 km ?). The pyroclastic activity, accumulation of the tuffs (and subsidence of the fill of the diatremes ?) were followed by the emplacement of the rhyolitic magmas, which largely formed various subvolcanic intrusions (Grocholski, 1965; Nemec, 1979, 1981a). The structure and evolution of the considered diatremes support their interpretation as the roots of maars or similar volcanoes (Lorenz *et al.*, 1970; Francis, 1970; Fisher & Schmincke, 1984; Cas & Wright, 1987).

Because of their geological position the volcaniclastic rocks of the Rusinowa–Grzmiąca belt cannot be interpreted as being contemporaneous with their country rocks. The available evidence does put some constraints on the likely age of the main volcanic events. The increased abundance of acid volcanic rock fragments within conglomerates of the Żacler Formation adjacent to the Rusinowa-Grzmiąca belt suggests that the activity commenced in the Westphalian (Grocholski, 1965; Nemec, 1979; Mastalerz, 1996 b). However, the stratigraphic position of the tuffs within the diatremes, above deposits tentatively correlated with the Glinik Formation, is equivalent to that of the Kamionki tuffs, intercalated in the upper part of the Glinik Formation outside the diatremes. It is thus considered that the main, pyroclastic activity within the Rusinowa-Grzmiąca belt was contemporaneous with the deposition of the Glinik Formation (late Westphalian to early Stephanian). Most probably, the rhyolitic, and then trachyandesitic intrusions (see below) quickly followed the explosive eruptions. Renewed volcanism along the southern prolongation of the Rusinowa-Grzmiąca belt occurred in Permian times (compare chapters on the Rybnica Leśna volcanic association and the Góry Suche rhyolitic tuffs).

Rusinowa-Grzmiąca Trachyandesites (RGTa)

There are 17 small trachyandesite bodies within the Rusinowa-Grzmiąca belt, most of them in its southern part (Fig. 11). The trachyandesites are generally found within the volcaniclastic rocks, but a few also occur within the rhyolites. The only known trachyandesite(?) occurrence outside the Rusinowa-Grzmiąca belt is a problematic sill or lava flow on Barbarka hill to the west, recognised in pits only (Grocholski, 1965; Bossowski *et al.*, 1994).

The outcrops of the trachyandesites are oval to aligned, 50 to 350 m long, and exceptionally more than 700 m long. One of the largest trachyandesite bodies, c. 250 m across, is well exposed in an abandoned quarry in the middle part of the Rusinowa-Grzmiąca belt (locality 4, Fig. 14). The trachyandesites are largely massive rocks, with irregular to blocky joints. Platy joints and vesicular lithologies are characteristic of the marginal zone of the igneous body, and trachyandesite-mudstone breccias occur at its top. The top of the trachyandesites dips at c. 40° eastwards, and is generally conformable with the overlying red-coloured mudstones, sandstones and conglomerates, overlain by the rhyolitic tuffs. However, the stratification of this sequence is disrupted: the sandstone and conglomerate layers are discontinuous, and trachyandesite blocks and tuff rafts are enclosed within the mudstones. A pipe-like apophyse, tens of metres long, projects upwards from the main trachyandesite body, cuts the overlying deposits and is exposed above the quarry. In the southernmost part of the quarry the trachyandesites are cut by a subvertical, c. 5 m thick clastic dyke. It shows subvertical banding and is filled with breccias (composed of trachyandesite fragments in a sandy matrix) and tuffaceous sandstones.

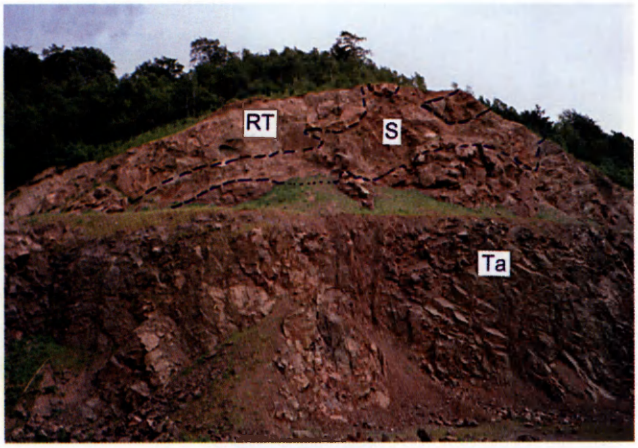

Fig. 14. A general view of a c. 50 m high abandoned quarry on the western slopes of Niedźwiadki hills, Wałbrzych-Podgórze (locality 4, Figure 11). Trachyandesites (Ta) form an dome-like intrusion within a sequence of sedimentary rocks (S) and rhyolitic tuffs (RT). Details in the text.

Interpretation. The trachyandesites have previously been considered to be plugs and intrusive sheets of Permian age (Grocholski, 1965; Nemec, 1979). However, the evidence described above strongly suggest the best exposed trachyandesite body (locality 4) is an endogenous dome of late Carboniferous age. It is considered here that the dome intruded into the red coloured clastics (tentatively correlated with the Glinik Formation) overlain by the rhyolitic tuffs, while these deposits were still unconsolidated (that is, shortly after their deposition). The intrusion disrupted the stratification of the sequence and caused a partial fluidisation of the deposits, with their injection as a clastic dyke into a fracture within the dome. In this context, a late Carboniferous age for the other trachyandesite occurrences in the Rusinowa-Grzmiąca belt seems likely, although their geological forms remain poorly constrained.

LOWER PERMIAN VOLCANIC COMPLEX

GÓRY KRUCZE VOLCANIC ASSOCIATION

Kamienna Góra basaltic trachyandesites (KGBTa)

The Kamienna Góra basaltic trachyandesites were extensively described in Awdankiewicz (1997 c) and Awdankiewicz *et al.* (1998) and a brief summary is given below. These rocks outcrop in the lowermost part of the Slupiec Formation, between Przedwojów and Kamienna Góra to the west and Czarny Bór and Grzędy to the east (Fig. 15). The basaltic trachyandesites attain their greatest thickness of c. 50–70 m in the middle part of their outcrop and wedge out SW- and SE-wards, where they interdigitate with sedimentary rocks and, near Przedwojów, with rhyolitic breccias. West of Czarny Bór and Borówno, thin basaltic trachyandesite sheets also occur near the top of the underlying Krajanów Formation (J. Don, unpublished data).

The main lithologies of the basaltic trachyandesites are massive to vesicular or amygdaloidal lavas and their breccias, and lava-sediment breccias. Based on a characteristic vertical succession of these lithologies, four main types of lavas were distinguished (Fig. 16). Lithological boundaries within the lava sheets are largely gradational, while contacts between igneous bodies are sharp. In most localities several successive lava sheets of various types, with sandstone and tuff intercalations, are observed (Fig. 17). In the central part of the area (localities 8 to 11, Fig. 17) adjacent sections can be correlated and their component lava sheets can be laterally

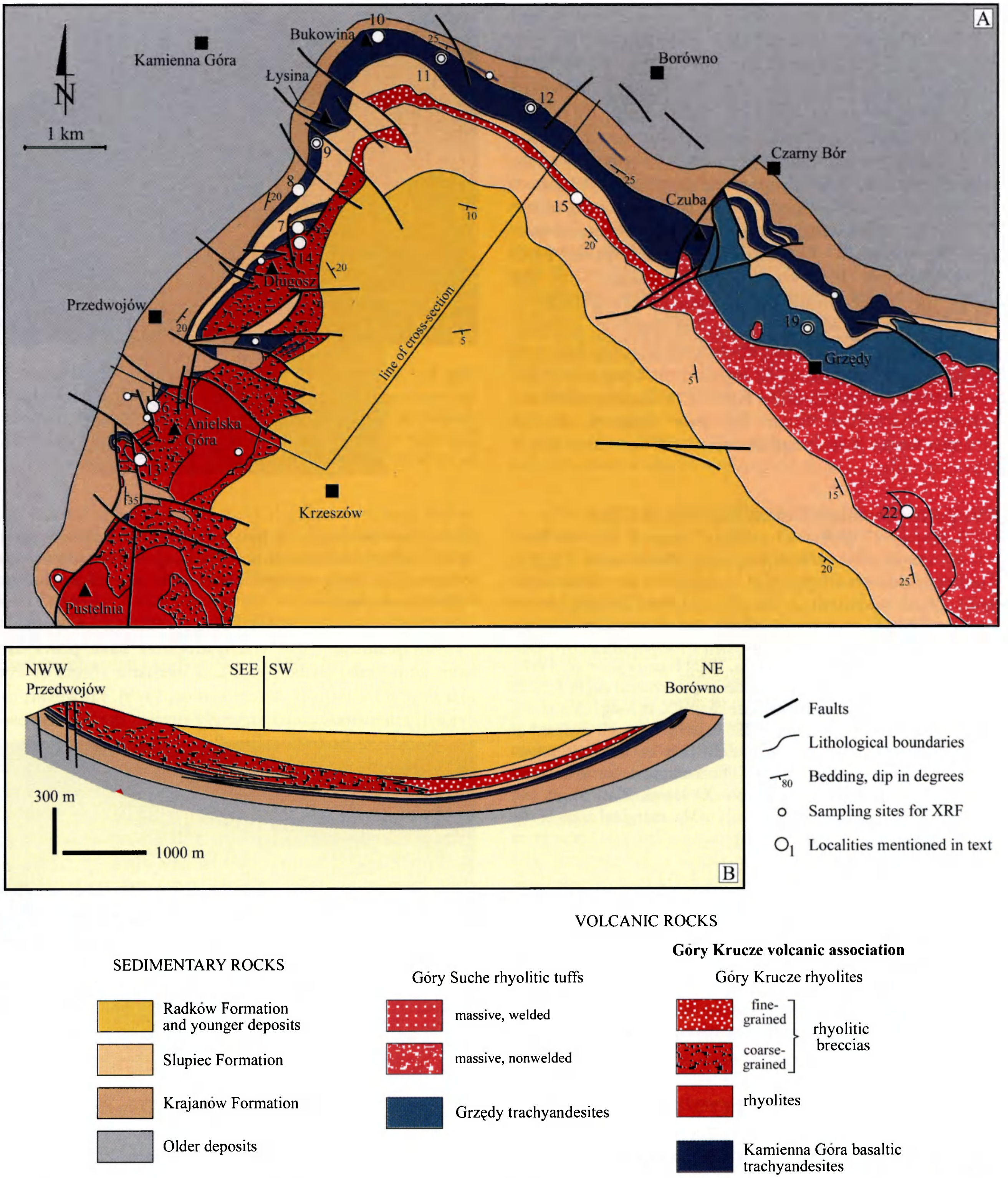

Fig. 15. A – Geological map of northern part of the Góry Krucze volcanic association (modified from Don et al., 1981 a; Grocholski, 1973 a; Mastalerz et al., 1995 a). B – cross-section of the association between Przedwojów, Krzeszów and Borówno.

traced for a few kilometres.

The most complex sequence at locality 9 consists of three successive lava sheets (B, C and A) with sandstone and tuff intercalations (Fig. 18). The lowermost lava sheet shows an uneven top and it is overlain by red-brown, poorly consolidated, wavy laminated sandstones (Fig. 19). The sandstones are poorly sorted and contain abundant clasts of vesicular basaltic trachyandesites (petrographically equivalent to the underlying lavas) and calcite cement. They are overlain by red-brown tuffs, with subhorizontal to wavy and low-angle cross lamination. The dip of the lamination suggest a W- to NW-ward transport directions of the tuffs. The tuffs are well sorted and composed of vesicular basaltic trachyandesite shards with chalcedony and kaolinite cement. Greenish sandstones (sublithic arenites) form thin, discontinuous

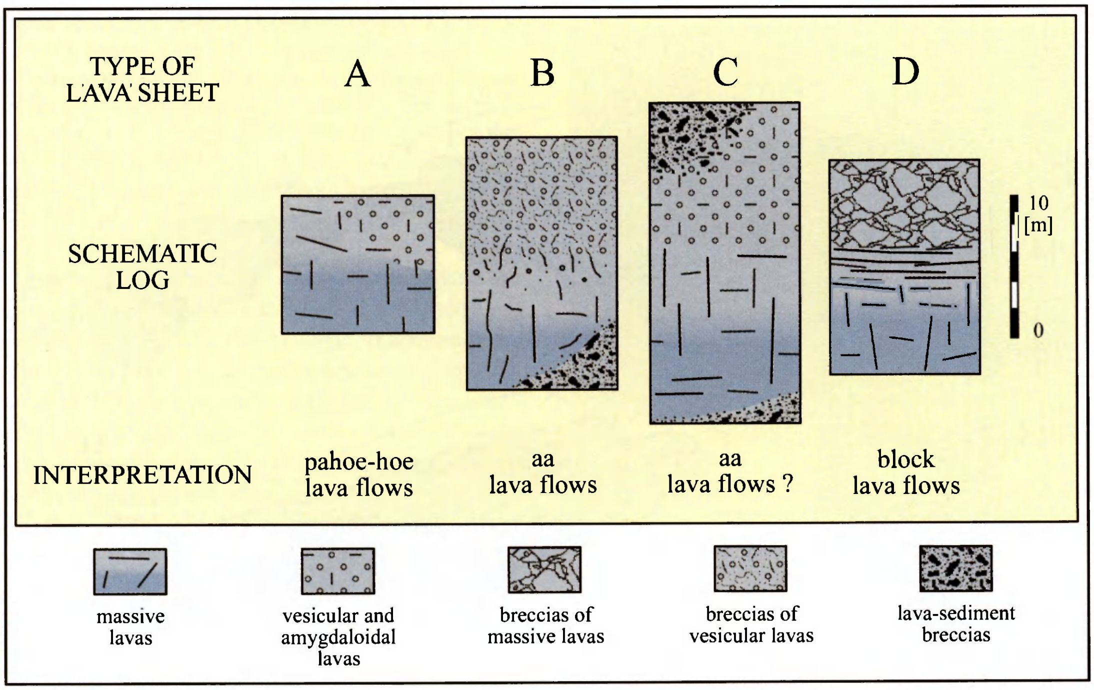

Fig. 16. The main types of lava sheets of the Kamienna Góra basaltic trachyandesites.

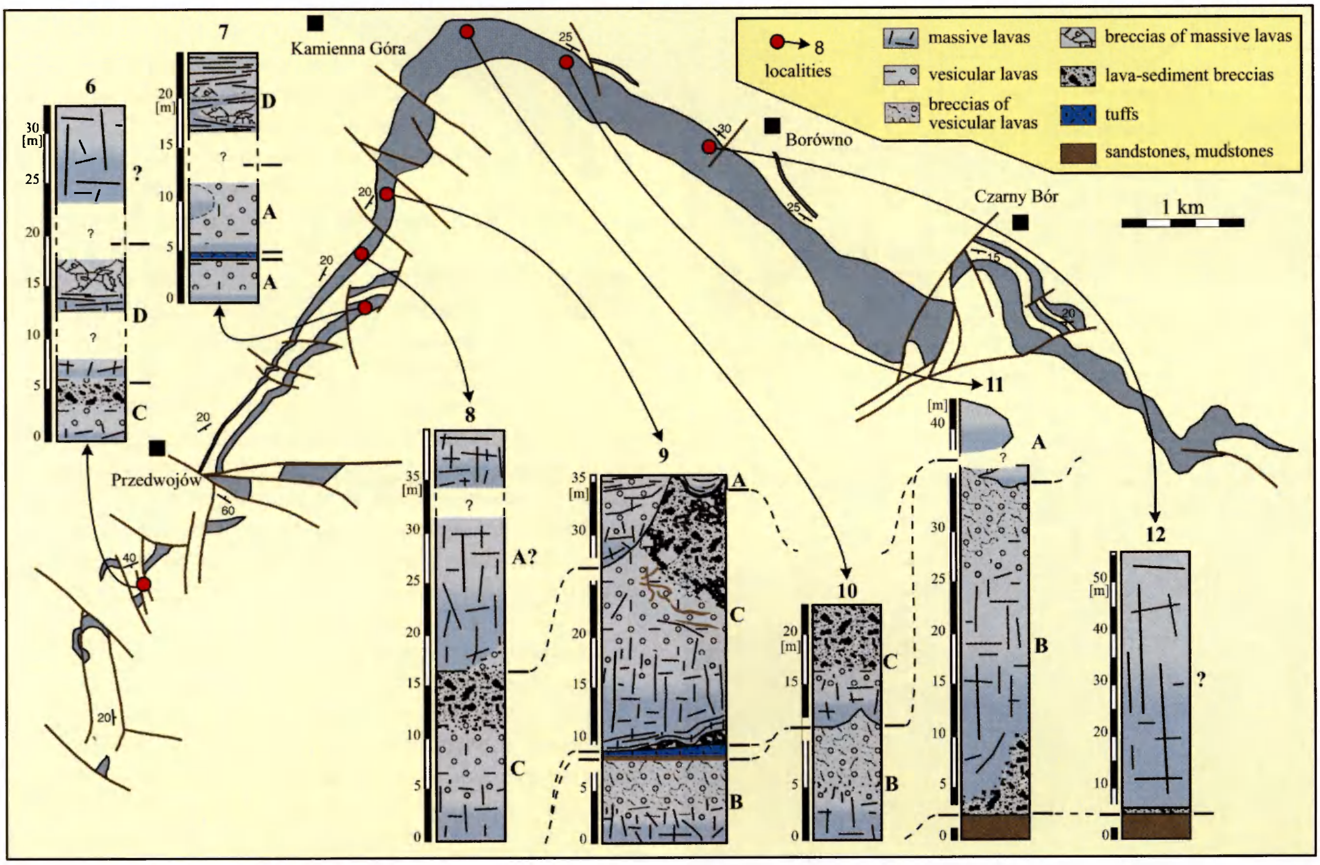

Fig. 17. Detailed logs of the Kamienna Góra basaltic trachyandesites. Discussion and interpretation in the text.

laminae at the base of the tuffs and 1–2 cm thick clastic dykes cutting the tuffs.

The c. 25 m thick "C" type basaltic trachyandesite sheet which overlies the tuffs consists of discontinuous, marginal zones of lava sediment-breccias (Fig. 19 and 20) and a vesicular to massive interior. The vesicular lavas host abundant blocks, rafts (up to 0.5 m thick and 8 m long) and clastic dykes (up to 20 cm thick) of greenish to brown sandstones (Fig. 21). The described lava sheet contains oval domains, 5–20 m in diameter, with massive cores and radial and/or concentric joint patterns (e.g. the central

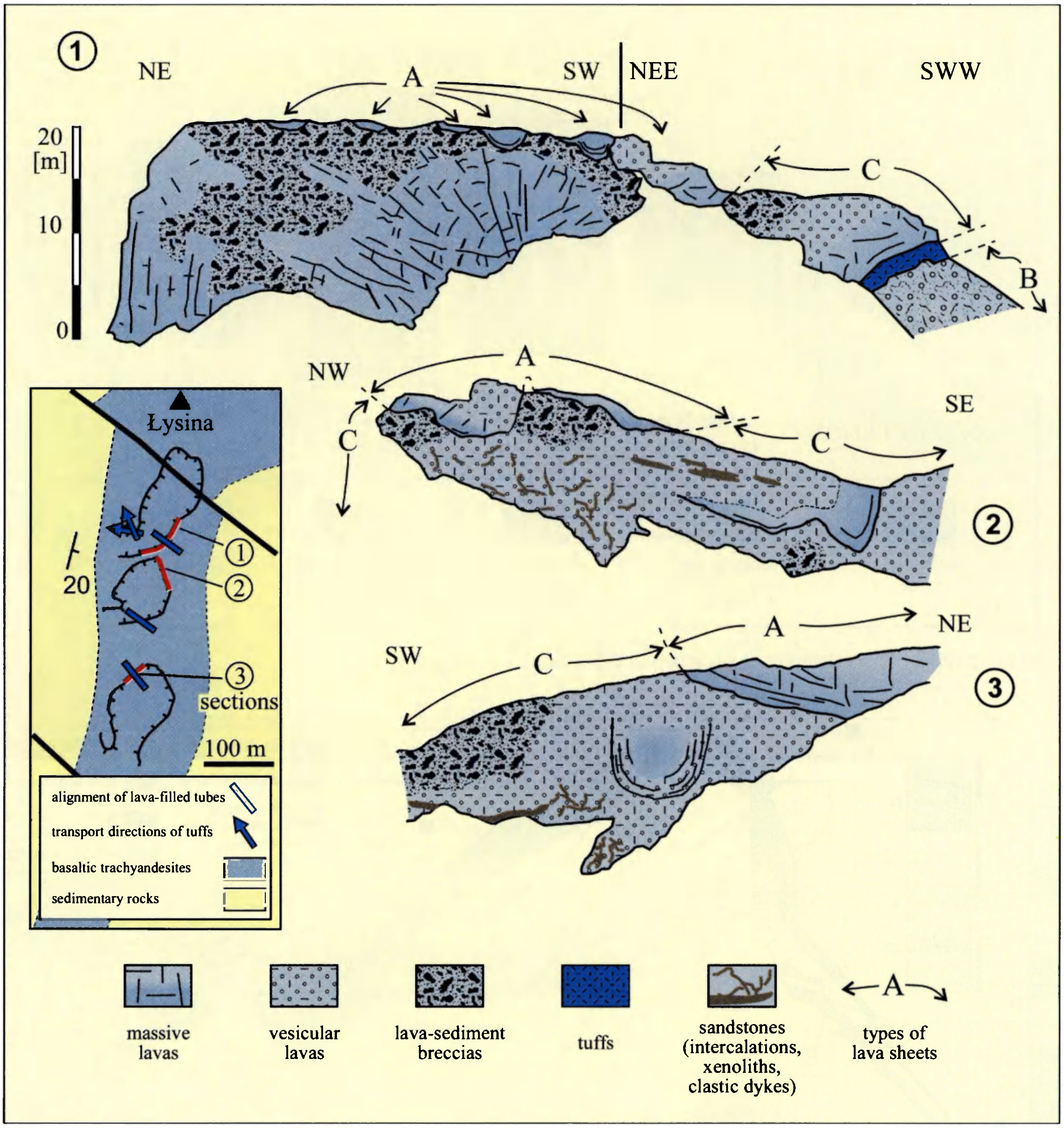

Fig. 18. Kamienna Góra basaltic trachyandesites. Structure of lava sheets in abandoned quarries at Lysina hill, SE of Kamienna Góra (locality 9, Fig. 17). Details in the text.

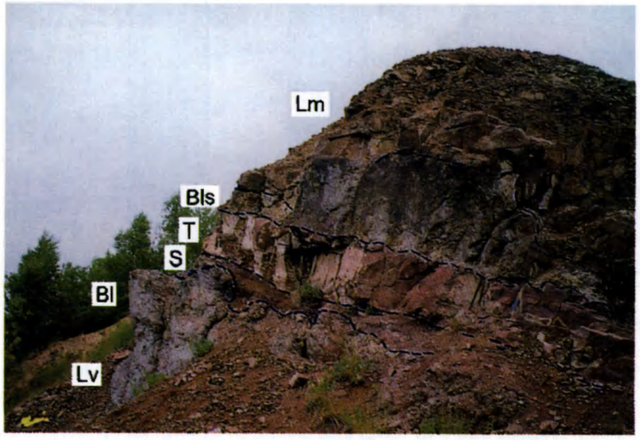

Fig. 19. Kamienna Góra basaltic trachyandesites. The photo shows lavas, tuffs and sedimentary rocks in the lower part of the sequence at Lysina hill, SE of Kamienna Góra (locality 9, Fig. 17). Lithologies: Bl – lava breccias, Bls – lava-sediment breccias, Lm – massive lavas, Lv – vesicular lavas, S – sandstones, T – tuffs. Description and interpretation in the text.

parts of sections 1 and 3, Fig. 18) that possibly represent transverse sections of NW–SE aligned structures within the lava sheet.

The uppermost part of the considered sequence is a discontinuous horizon of A-type lavas (Fig. 18 and 22). The form of these lavas ranges from thin sheets to NW–SE aligned, thick lobes (Fig. 22), with platy joints subparallel to their base and margins and sharp, uneven basal contacts, reflecting the basement morphology.

Emplacement and depositional mechanisms. Based on analogies with modern basaltic lava flows (e.g. Macdonald, 1967; Cas & Wright, 1987) the basaltic trachyandesite sheets (Fig. 16) are interpreted as pahoe-hoe lavas (type A), aa lavas (type B and C) and block lavas (type D). The basaltic trachyandesite breccias typical of sheets B and D represent autoclastic deposits. The lava-sediment breccias characteristic of sheets C and B are possibly of a more complex origin and, together with blocks, rafts and dykes of clastic rocks found within the lavas, represent the effects of both autoclastic processes and lava-wet sediment interaction (Kokelaar, 1982). Such interactions might have occurred during lava flowage over water-saturated, unconsolidated sediments (sheets B) or during the eruption of lava through a cover of wet sediments and further flowage (sheets C). Although sheets C also resemble shallow level sills emplaced into poorly lithified sediments (Kokelaar, 1982; Walker & Francis, 1987), their position in the described sections, within sequences of lavas and tuffs, seems more consistent with their interpretation as lava flows. The NW–SE aligned domains within the sheet C at locality 9 possibly represent relics of lava tubes – former distributary channels of lava within the flow.

The sedimentary and volcaniclastic rocks interstratified with the lavas are of variable origin. The red brown sandstones with abundant clasts of vesicular lavas (localities 9 and 7) possibly originated due to a redeposition of local, fine grained volcaniclastic detritus derived from weathering of the underlying lavas. The greenish sandstones, which lack basaltic trachyandesite clasts, compare well with deposits of the upper part of the Słupiec Formation (the Walchia shales, Mastalerz *et al.*, 1995 b) and probably represent alluvial and/or lacustrine sediments, accumulated during periods of volcanic quiescence. The laminated tuffs are interpreted as pyroclastic surge (and/or fall ?) deposits, related to episodic explosive eruptions of the basic magmas.

Style of activity, location and type of the volcano. The considered sequence of basaltic trachyandesites compares well to a small Icelandic type shield volcano (Cas & Wright, 1987) or a monogenetic scutulum type lava shield (Walker, 1993). Such volcanoes have the shape of very flat cones, a few km wide at the base and up to a few hundred meters high. Their activity is dominated by lava effusions, forming lava shields surrounding the central vent, with episodic phreatomagmatic eruptions and accumulation of thin layers of tuffs. The Kamienna Góra basaltic trachyandesites fit these characteristics well. Assuming a central position for the vent and a symmetric, radial distribution for the lavas, the basal diameter of the volcano may be estimated at about 12 km in that case (the extent of the out-

Fig. 20. Kamienna Góra basaltic trachyandesites. Breccia composed of lava and sandstone blocks at Łysina hill, SE of Kamienna Góra (locality 9, Fig. 17).

Fig. 21. Kamienna Góra basaltic trachyandesites. Sandstone rafts (S) within vesicular lavas (Łv) in the middle part of the sequence at Łysina hill, SE of Kamienna Góra (locality 9, Fig. 17).

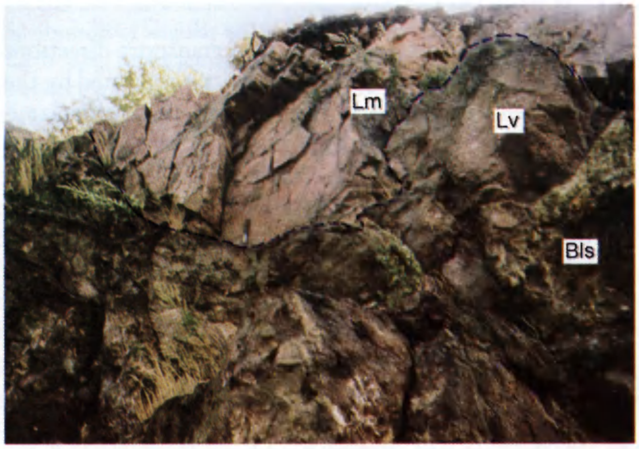

Fig. 22. Kamienna Góra basaltic trachyandesites. The uppermost part of the sequence at Łysina hill, SE of Kamienna Góra (locality 9, Fig. 17). Massive lavas (Łm) overlying vesicular lavas (Łv) and lava-sandstone breccias (Bls).

Fig. 23. Góry Krucze rhyolites in an abandoned quarry on the southern slopes of Anielska Góra hill near Przedwojów (locality 13, Fig. 15). The photo shows coarse-grained, poorly sorted breccias with a chaotic structure, composed of subangular to subrounded blocks of massive rhyolites. The coin is 24 mm in diameter.

crop) and its height at about 100 m (approximate maximum thickness of the lavas), giving the average slope of c. 1° and a total volume of the volcano of c. 4 km^3.

The location of the main vent of the volcano in the central part of the considered unit, SE of Kamienna Góra, in the area now covered with younger deposits, is supported by the following evidence:

- the lack of discordant intrusions (dykes or necks), the former feeders of the volcano, within the basaltic trachyandesite outcrop and within the underlying sequence,

- the thicker intercalations of sedimentary rocks in the marginal (southern and eastern) parts of the basaltic trachyandesite outcrop, and greatest facies variation (e.g. greatest number of diverse flows, tuff intercalations) in the central part of the outcrop, are consistent with their interpretation as, respectively, the distal and proximal parts of the volcano,

- a westward to north-westward transport directions for the lavas and the pyroclastic deposits is indicated by the alignment of lava tubes and the dip of low-angle cross lamination at locality 9, NW of the supposed vent.

The stratigraphic distribution of basaltic trachyandesites and the correlation of lava sequences suggest that the oldest lavas occur in the E–NE part of the volcano, while the youngest are found to the W–SW (Fig. 17). Such a distribution of the successive flows may reflect a palaeogeographic control on lava flow directions and/or SW-ward vent migration. The main vent was possibly located on a SE-wardly inclined, gentle palaeoslope, and the oldest lavas preferably flowed to the east. Aggradation of relief due to the accumulation of successive flows pushed the younger lavas northwards and then westwards. At the late stages of activity it is possible that a new vent opened to the SW, as suggested by the distribution of the youngest lavas east of Przedwojów. Interdigitation of basaltic trachyandesites and rhyolitic breccias in the latter area possibly results from the deposition of the rhyolitic breccias in depressions within a discontinuous cover of older basic lava flows (or, less probably, from contemporaneous basic and acidic volcanism).

Góry Krucze rhyolites (GKR)

The Góry Krucze rhyolites form an extensive outcrop along the western limb of the Intra-Sudetic Basin. They attain their greatest thickness of about 500–700 m west of Chełmsko Śląskie, and northwards gradually wedge out, down to 200–300 m near Przedwojów and c. 50 m near Czarny Bór (Fig. 15). Within the study area the rhyolites occur above the Kamienna Góra basaltic trachyandesites, within sandstones and mudstones of the upper part of the Słupiec Formation, corresponding to the Walchia Shales (Mastalerz *et al.*, 1995 a, b). Southwards, the sedimentary rocks and the basaltic trachyandesites wedge out and the rhyolites unconformably overlie deposits of the lower part of the Krajanów Formation, and are unconformably overlain by the Radków Formation. The latter contains abundant detritus apparently derived from the Góry Krucze rhyolites.

The rhyolites are made up of massive lavas, coarse-grained breccias, fine-grained breccias and sandstones. The massive rhyolites predominate in the south, but northwards, with decreasing thickness, the coarse-grained breccias and then the fine-grained breccias and sandstones become more abundant (Awdankiewicz *et al.*, 1998). In several localities a gradation from massive to highly cracked rhyolites and to rhyolitic breccias is observed, and various types of rhyolitic breccias probably interdigitate in the northern part of the Góry Krucze rhyolites. Vesicular lavas occur locally as small lenses within the massive rhyolites.

The massive rhyolites show platy joints and locally indistinct flow banding and small flow folds. The coarse-grained rhyolitic breccias are characterised by an open to compact framework and consist of angular to subangular rhyolite blocks up to 50 cm in size, rare quartz pebbles and subangular trachyandesite (?) clasts and calcite or barite cement (Fig. 23). They usually form chaotic accumulations tens of metres thick, with irregular joints (e.g. locality 13), but in places show gently inclined amalgamated bedding, with individual beds 15–60 cm thick (e.g. locality 14). The fine-grained rhyolitic breccias at locality 15 form a 4 m thick, massive bed characterised by an open framework that consists of aligned rhyolitic fragments, up to 15 mm long. Subordinate components are mudstone and phyllite clasts and the sandy matrix is composed of angular fragments of rhyolite, quartz and feldspars, white mica and biotite flakes and clay minerals cemented with chalcedony. The rhyolitic sandstones, observed in loose blocks only, lithologically resemble the matrix of the above described breccias.

Interpretation. The Góry Krucze rhyolites have recently been interpreted as a large, asymmetric effusion of composite structure (Awdankiewicz *et al.*, 1998). The eruption centre was possibly located west of Chelmsko Śląskie, where the rhyolites are thickest. The lava flowed mainly north- and eastwards, towards the centre of the Intra-Sudetic Basin. The core and proximal parts of the effusion are mainly composed of massive lavas with the greatest petrographic variation within the complex. The upper and distal parts contain larger proportions of vesicular rhyolites and rhyolitic breccias. The structural and lithological variation of the latter reflect variable modes of fragmentation of rhyolitic lavas and redeposition of the detritus. The main genetic breccia types possibly include:

1) autoclastic breccias formed by mechanical crushing of lava on flowage (the coarse-grained breccias with a com-

pact framework, gradational into massive lavas),

2) talus breccias formed by tumbling of rhyolitic clasts in frontal parts of lava flows (the coarse-grained breccias with closed to open framework),

3) epiclastic breccias formed by a mass redeposition and/or fluviatile redeposition of the rhyolitic detritus (the coarse grained breccias with indistinct bedding and the fine-grained breccias with sandy matrix).

Some of these breccias may also represent pyroclastic deposits originated from small block and ash flows related to a gravitational collapse or explosive disruption of marginal parts of lava flows and domes.

Accumulation of the breccias was contemporaneous with, or quickly followed, the emplacement of the rhyolitic lavas. However, the abundant rhyolitic detritus in the overlying Radków Formation reflects a significant subsequent erosion of the Góry Krucze rhyolites.

UNISLAW ŚLĄSKI VOLCANIC ASSOCIATION

Łesieniec-Sokołowsko basaltic trachyandesites (ŁSBTa)

The Lesieniec-Sokołowsko basaltic trachyandesites comprise several small outcrops in the lowermost part of the Unislaw Śląski volcanic association, within sandstones and mudstones of the Slupiec Formation (Fig. 24). Near Stary Lesieniec the basaltic trachyandesites form conformable and discordant sheets, up to c. 100 m thick and over 1 km long, largely composed of massive, locally brecciated lavas. West of Unislaw Śląski there are several conformable basaltic trachyandesite sheets, 50 m to 800 m long and up to 15 m thick, which consist of massive to vesicular lithologies and breccias of lava fragments in a silty matrix at their margins (Grocholski, 1973 b, p. 34). In the vicinity of Sokołowsko small, oval outcrops of the basaltic trachyandesites form two linear, "en echelon" belts, subparallel to adjacent NNW-trending faults. The main lithologies are massive basaltic trachyandesites in the south and their breccias in the north. The dominant coarse-grained breccias are characterised by a compact framework and consist of massive, angular lava blocks up to 0.5 m in size. Near the margins of the outcrops there are pockets and veins of finer-grained breccias with an open framework and a "fluidal" arrangement of larger clasts in a matrix of detritial quartz and micas with abundant haematite-stained calcite cement.

Interpretation. The Unislaw-Sokolowsko basaltic trachyandesites show many structural and lithological analogies with the Kamienna Góra basaltic trachyandesites (Awdankiewicz, 1997 c). The exposure of the former is worse, and the emplacement mechanism and geological forms of several of these igneous bodies cannot be easily determined. However, the massive and partly discordant sheets near Stary Lesieniec may largely represent subvolcanic intrusions (inclined sheets and sills), while the highly vesicular, conformable sheets near Unislaw Śląski possibly represent lava flows similar to types A and C of the Kamienna Góra region. As in Grocholski (1973 a, b, 1981) basaltic trachyandesites from Sokolowsko are interpreted as lava- and breccia-filled plugs. The breccias are largely of autoclastic origin, although those with a sedimentary matrix found at the margins of the plugs might have originated due to lava-wet sediment interaction.

The discontinuous, patchy outcrop pattern of the Unislaw-Sokolowsko basaltic trachyandesites suggests that these rocks represent either 1) a distal part of a small shield volcano with the main eruption centre to the SW, or 2) a volcanic field with a number of small vents. The linear arrangement of the plugs near Sokolowsko indicates that NW-SE to NNW-SSE faults controlled the magma ascent paths.

Stożek Wielki trachyandesites (SWTa), Dzikowiec rhyolites (DR), Ługowina rhyolites (ŁgR) and Waligóra rhyolites (WR)

The Stożek Wielki trachyandesites together with the Dzikowiec and Lugowina rhyolites represent the core of the Unislaw Śląski volcanic association and form a compact, NNW-SSE aligned outcrop, c. 6 km long and up to 2 km wide (Fig. 24). These volcanic rocks are unconformably overlain by the Góry Suche rhyolitic tuffs (details are discussed further in the paper).

The thickness of the trachyandesites ranges from about 200-300 m in the NW, up to, possibly, twice as much, in the SE. The lower and central parts of the complex show massive structure and weak lithological variation, while its upper and marginal parts are characterised by interdigitation of the trachyandesites, rhyolites, and sedimentary rocks of the Slupiec Formation, as well as greater lithological variation. Massive to weakly brecciated trachyandesites and rhyolites represent the main lithologies, and to the NW and SE they locally grade into vesicular lavas and mudstone-trachyandesite breccias composed of sedimentary rock fragments set in a lava matrix (Grocholski, 1973 a, b).

The Waligóra rhyolites form a separate igneous body, c. 3 km long, in the easternmost part of the Unislaw Śląski volcanic association. Their outcrop pattern suggests a gradation from a semiconformable, over 500 m thick dome into a conformable, 100-150 m thick sheet in the westernmost part. The dominant lithology is a massive, densely cracked rhyolite. The western part of the outcrop shows greater structural and lithological variation, with platy-jointed lavas near the base of the rhyolite sheet (locality 16), flow-banded, vesicular rhyolites in its upper part (locality 18) and irregular pockets and veins of rhyolitic breccias, cm to dm wide, both near the top and the base (localities 16 and 17). The breccias are characterised by an open framework and a chaotic distribution of angular to subrounded rhyolite fragments, up to 10 cm long, in a haematite-rich, quartzo-feldspathic matrix. The phenocryst content of the rhyolites gradually decreases from 10-15 % on Waligóra hill down to c. 2 % further west.

Interpretation. The considered trachyandesites and rhyolites are interpreted as a composite, multivent volcano, composed of closely spaced lava domes and, possibly, short flows. The relatively weak lithological variation of the volcanic rocks, compared e.g. with that of the Góry Krucze rhyolites and other intermediate-acidic lava complexes (e.g. Cas & Wright, 1987; Howells *et al.*, 1991), suggests a largely transitional, endogenous to exogenous emplacement of the lavas. The main vents are possibly concealed beneath the thickest accumulation of the volcanic rocks SW of Stożek Wielki and Mały hills, but other, smaller vents were probably active in the NW part of the volcano. The Waligóra rhyolites rather erupted from a separate vent near the eastern margin of their outcrop, as suggested by the asymmetric variation of thickness, lithology and petrography of the rhyolites.

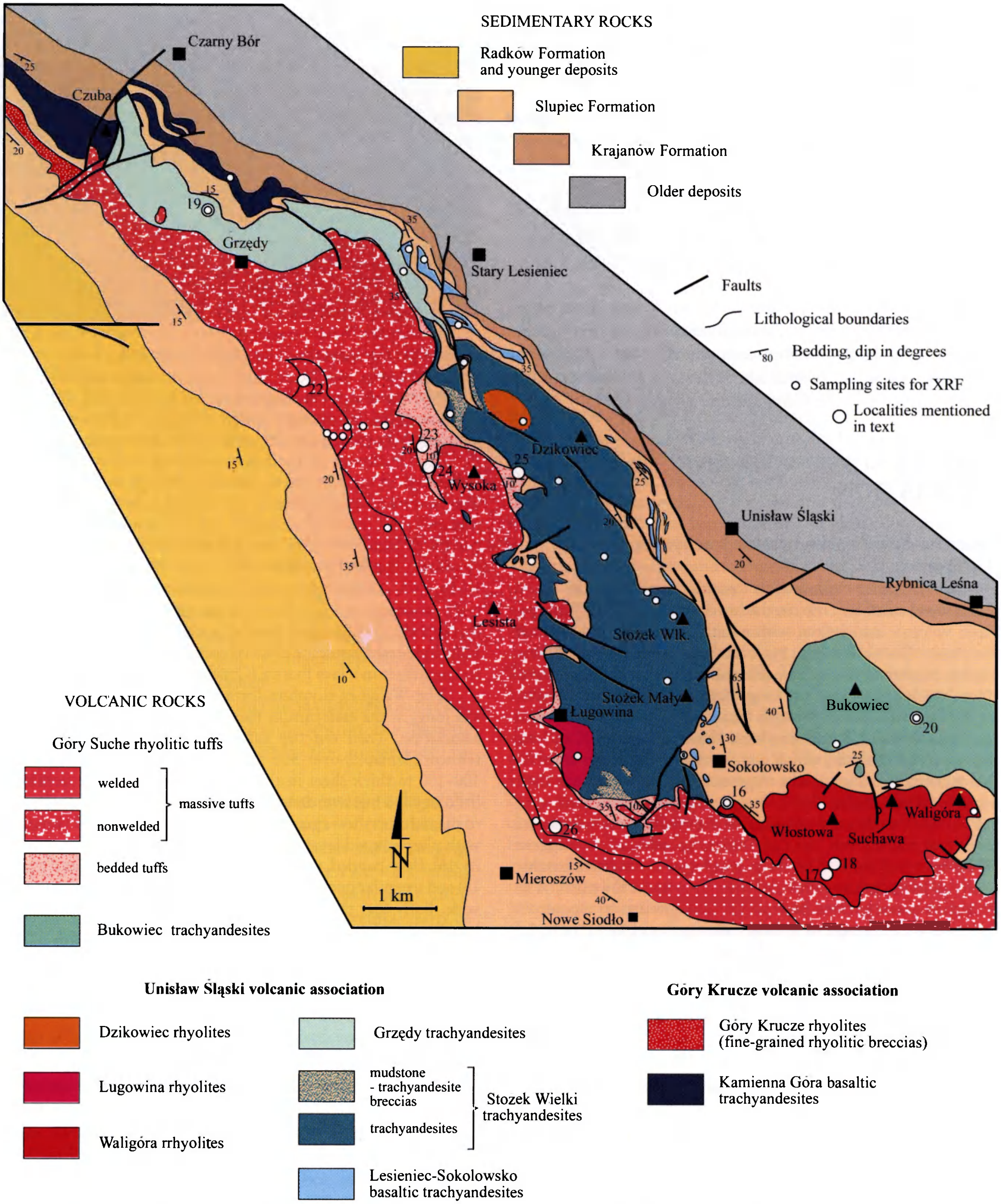

Fig. 24. Geological map of the Unisław Śląski volcanic association (modified from Grocholski, 1973 a; Bossowski & Czerski, 1987; Mastalerz et al., 1995 a; Bossowski et al., 1994).

The emplacement of the considered trachyandesites and rhyolites postdated the basic volcanism in the area (Lesieniec–Sokołowsko basaltic trachyandesites). Subsequently, the volcano was partly eroded and buried beneath the Góry Suche rhyolitic tuffs. The above conclusions are generally consistent with the earlier interpretations of Grocholski (1973 a, b, 1981).

Grzędy trachyandesites (GTa)

The Grzędy trachyandesites form a conformable sheet extending for about 5.5 km between Mały Dzikowiec hill in the SE and Czuba hill in the NW and up to c. 100 m thick to the west (Fig. 24). The trachyandesites are underlain by sandstones and mudstones of the Słupiec Formation and overlain by similar deposits or directly by the Góry Suche rhyolitic tuffs. The trachyandesites and their country rocks are best exposed in an extensive quarry NW of Grzędy (locality19, Fig. 25). The underlying sedimentary rocks (Fig. 26) show deformations (brecciation of sandstones, thrust folds and faults in mudstone and siltstone intercalations) and incipient hydrothermal alterations (local silification

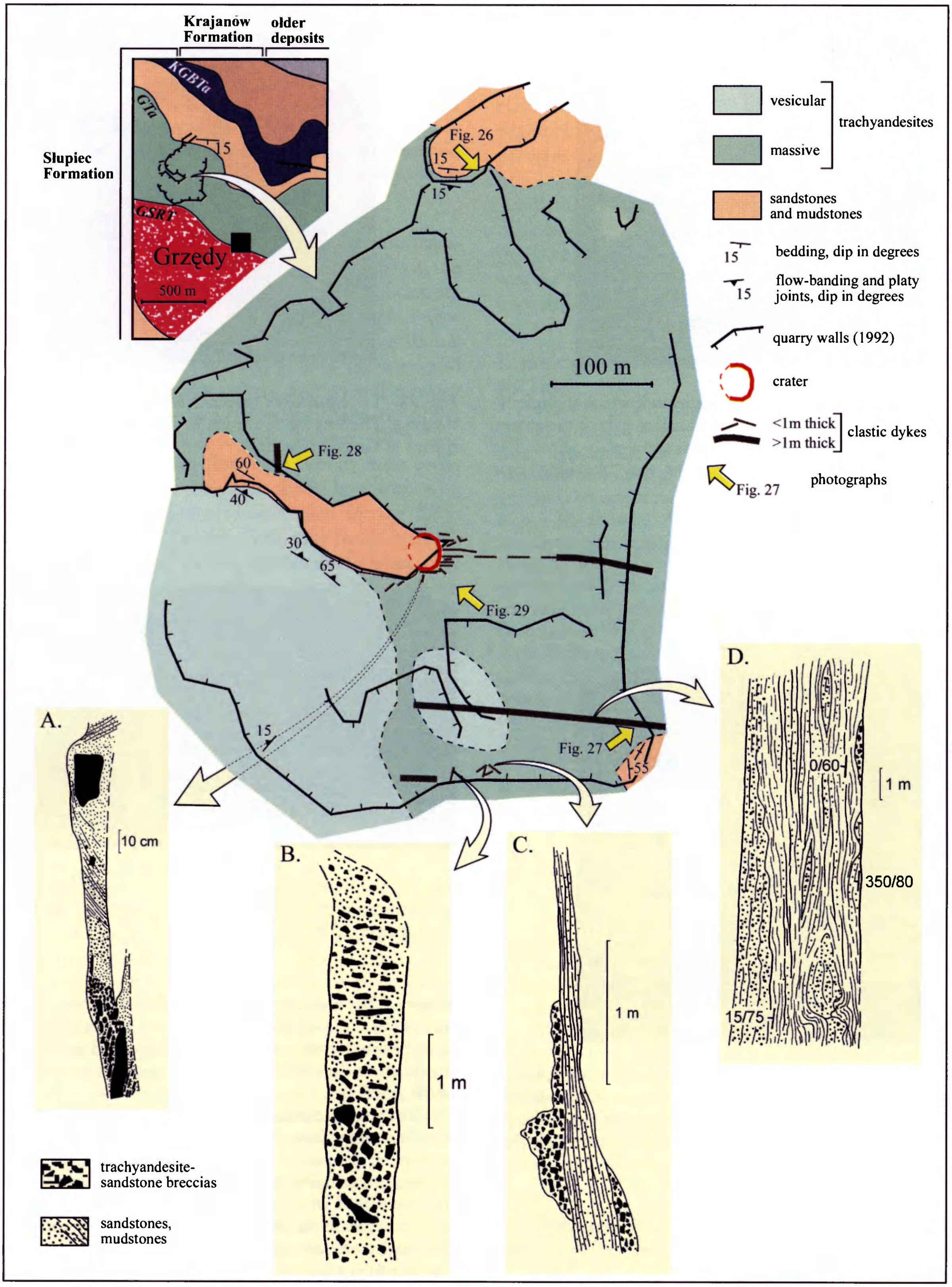

Fig. 25. Geological sketch of the trachyandesite quarry near Grzędy village (locality 19, Fig. 24) and structures of the clastic dykes (A–D) cutting the trachyandesites.

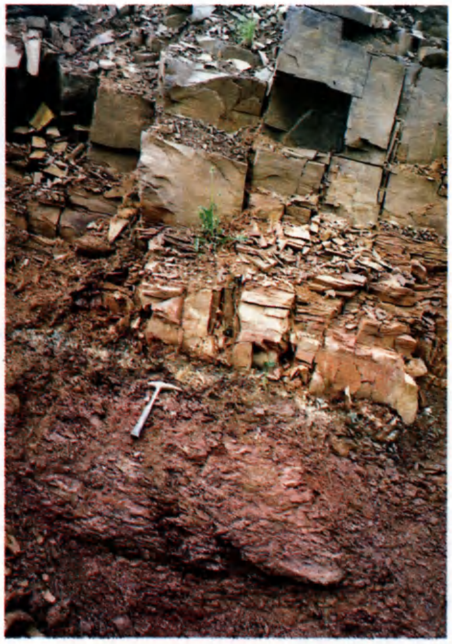

Fig. 26. A conformable contact of trachyandesites with underlying sandstones and mudstones in the northern part of the quarry at Grzędy (Fig. 25). The trachyandesites show platy joints. The sedimentary rocks show weak brecciation and "bleaching" near the base of the trachyandesites.

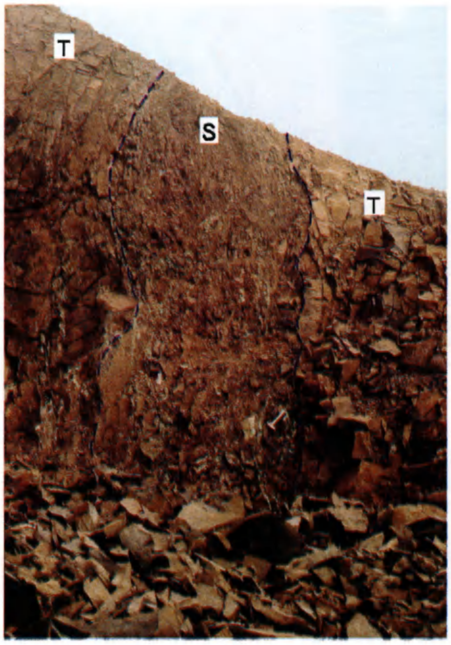

Fig. 27. A 2 m thick subvertical clastic dyke of banded, brown and green sandstones and mudstones (S) within blocky-jointed trachyandesites (T). Similar, thin clastic veins cut the trachyandesites left of the main dyke. SE part of the quarry at Grzędy (Fig. 25).

Fig. 28. Trachyandesite breccia with mudstone matrix in a clastic dyke. The lens cap is c. 5 cm in diameter. Central part of the quarry at Grzędy (Fig. 25).

Fig. 29. Central part of the quarry at Grzędy (Fig. 25). A c. 40 m high section of the middle-upper part of the trachyandesite sheet transected by the crater.

and "bleaching") within a 5-7 m thick zone adjacent to the trachyandesites. The lowermost, 5-10 m thick zone of the trachyandesite sheet is characterised by platy joints (Fig. 26). The over 30 m thick central zone consists of massive trachyandesites with subvertical platy joints, gradational into blocky and irregular joints. The c. 25 m thick upper zone is flow banded, with alternating massive, platy jointed and vesicular trachyandesite layers cm to meters thick. Strong brecciation is found in places. The top of the sheet possibly shows a wavy morphology, and in the SW part of the quarry it dips NE-wards, almost opposite to the general dip of the sequence.

The trachyandesites are cut by a swarm of clastic dykes (Fig. 25). The largest dykes, up to 5 m thick and 100-200 m long, are subvertical and east-west aligned, but most of them are an order of magnitude smaller and show a more variable orientation. The dykes are filled with sandstones (Fig. 27) or with breccias of angular trachyandesite blocks set in a sandstone matrix (Fig. 28). The sandstones are usually of sublithic/subarcosic composition, but in places their main components are vesicular silicic glass shards (devitrified, replaced by a fine-grained quartz aggregate) and embayed, broken quartz and feldspar phenocrysts. Most of the breccia dykes show a massive, chaotic structure, while the sandstone dykes are characterised by subvertical, lensoidal banding (Fig. 25, dyke D). Some thinner veins show more variable structures, e.g. "cross bedding", subhorizontal alignment of fragments, or irregular breccia pockets near the margins (Fig. 25, dykes A, B and C).

The upper part of the trachyandesite sheet is transected by a basin-shaped crater c. 40 m in diameter (Fig. 29). Trachyandesites adjacent to the crater are strongly brecciated and densely injected with clastic dykes. The crater is filled with red and green-coloured sandstones and mudstones with poorly defined centroclinal bedding. Similar deposits overlie the trachyandesite sheet to the west of the crater. These clastic rocks show a weak hydrothermal alteration (carbonatization and silification) along cm to dm wide, anastomosing veins within the crater and thinner, conformable bands within the sequence to the west.

Interpretation. The Grzędy trachyandesites are tentatively interpreted as a lava flow erupted from feeders in the central part of the Unislaw Śląski volcanic association, where compositionally similar extrusions outcrop (the Stożek Wielki trachyandesites). The westward thickening of the Grzędy trachyandesites, away from the supposed vent, resembles the thickness variation of several modern lava flows which become thicker towards shallower slopes at the feet of volcanoes (e.g. Cas & Wright, 1987). The clastic dykes transecting the flow near Grzędy most probably originated due to interaction of the lava with wet, poorly consolidated sediments overridden by the flow. Such interactions (e.g. Kokelaar, 1982) may result in fluidisation of sediments (due to the expansion of heated pore water), brecciation of lava (due to a thermal shock) and the injection of the clastic mixtures into fractures within the flow (e.g. along cooling joints). The crater most likely originated due to an explosion of overpressured steam derived from the wet sediments.

RYBNICA LEŚNA VOLCANIC ASSOCIATION

Bukowiec trachyandesites (BuTa)

The Bukowiec trachyandesites form several sheets interstratified with sedimentary rocks of the Slupiec Formation and dipping to the south (Fig. 30). Between Bukowiec and Klin hills to the west, a conformable trachyandesite sheet c. 200 m thick outcrops. Eastwards, around Klin and Turzyna hills, the base of the sheet becomes discordant: it is gently inclined (c. 5°) and cuts the underlying, more steeply inclined beds (20–25°) at a low angle. North-eastwards of Jeleniec hill, down the sequence, the inclined trachyandesite sheet possibly grades into a subvertical pipe, c. 100–250 m in diameter. Southwards, between the Waligóra and Łomnica rhyolites, the trachyandesites split into several conformable sheets, 50–150 m thick, that probably wedge out within 1–2 km.

The described sheets are largely composed of massive trachyandesites with blocky, irregular or platy joints. Locally the massive rocks grade upwards into vesicular trachyandesites. Thin (< cm), discontinuous breccia zones are exposed at the top of trachyandesite sheet at locality 20, at the contact with red mudstones. The breccias are composed of closely spaced angular trachyandesite fragments cemented with calcite. The mudstones are locally folded and silicified.

Interpretation. Kozlowski (1958, 1963) interpreted the considered trachyandesite sheets as successive lava flows, related to separate "volcanic cycles". However, the relationships discussed above are inconsistent with this interpretation and show that the trachyandesite sheets represent an intrusive complex of sills and inclined sheets (Fig. 30, section 1), grading northwards into a plug, the feeding conduit of the complex. Compared with the trachyandesite domes and lavas of the Unislaw Śląski volcanic association the Bukowiec trachyandesites show distinctive petrographic features indicating a slower cooling at a higher pressure (e.g. coarser-grained texture, scarcity of vesicular lithologies, amphibole overgrowths on pyroxenes; Awdankiewicz, 1997 a). The geological form and spatial relationships relative to adjacent volcanic bodies suggest that the emplacement of the Bukowiec trachyandesites was the youngest igneous event in that area, postdating the deposition of the Góry Suche rhyolitic tuffs.

Łomnica rhyolites (ŁR) and Głuszyca trachyandesites (GłTa)

The Łomnica rhyolites and Gluszyca trachyandesites form several intimately interstratified, flat lying, conformable, thick sheets gradational into domes or laccoliths, separated by thin mudstone and siltstone intercalations (Fig. 30). The outcrop pattern and contacts of the volcanic and sedimentary rocks observed in pits (Kozłowski, 1958) show that the trachyandesite sheets overlie the rhyolites, attain greatest thickness in places where the rhyolitic bodies are thinnest, and wedge out over the thickest parts of the rhyolitic domes (Fig. 30, section 2). However, an oval trachyandesite outcrop on the northern slope of Ostoja hill shows subvertical, discordant boundaries against the sedimentary rocks and represents a plug (Kozlowski, 1958). All the described igneous bodies in the vicinity of Łomnica are predominantly composed of massive rocks, with local brecciation at the contacts with mudstones and weak thermal alteration of the latter (Kozlowski, 1958).

The trachyandesites and their host rocks are best exposed in an over 300 m long and 100 m deep quarry near Gluszyca Górna (locality 21) and the relationships found there have been discussed by Kozlowski (1958, 1963) and Dziedzic (1980 b, 1981 a, b). In general, the trachyandesites form several semiconformable, lensoidal bodies grouped in two horizons, separated by sandstones and mudstones of the Slupiec Formation, with the Góry Suche rhyolitic tuffs at the top (Fig. 31). The sedimentary rocks are strongly folded, faulted and silicified and enclose isolated trachyandesite blocks adjacent to the main igneous bodies. The basal part of the tuffs is disrupted, with large tuff blocks set in a sedimentary matrix and sediment veins penetrating the tuffs. The trachyandesite bodies are largely composed of massive rocks with blocky and platy joints of variable orientation. The upper part of uppermost trachyandesite sheet consists of massive to vesicular, flow banded trachyandesites that grade into trachyandesite breccias with sedimentary matrix. At the SE end of the section the breccias, together with abundant clastic veins of mudstones, are also found within the trachyandesite sheet.

Interpretation. Kozlowski (1958, 1963) considered that the volcanic rocks between Gluszyca and Łomnica represent a sequence of lava flows and pyroclastic deposits erupted in two cycles, with the acidic rocks postdating the intermediate rocks in each cycle. However, Dziedzic (1980 b, 1981 a, b) suggested an intrusive origin of all these vol-

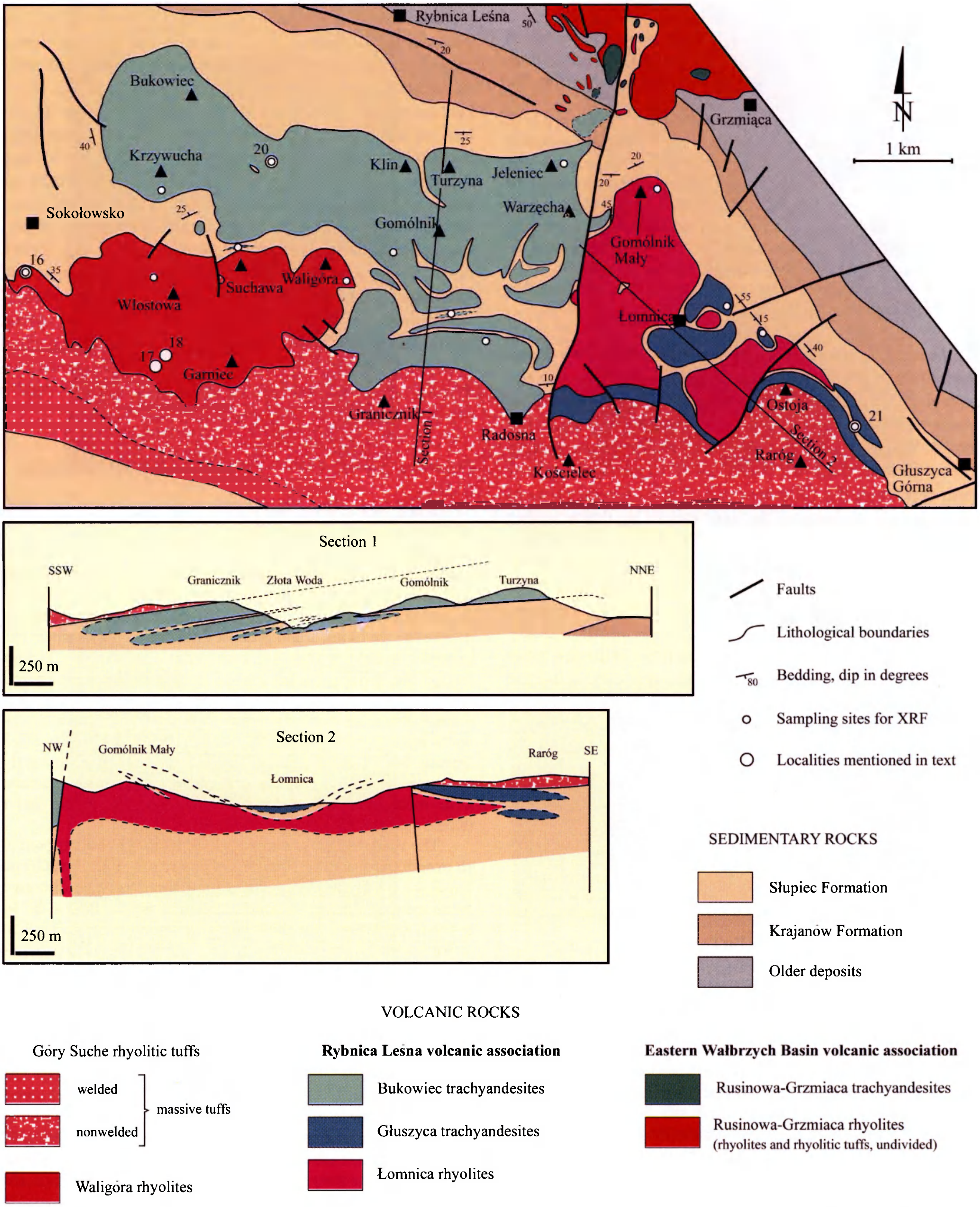

Fig. 30. Geological map and cross-sections of the Rybnica Leśna volcanic association (map modified from Grocholski, 1973 a and Bossowski *et al., 1994).*

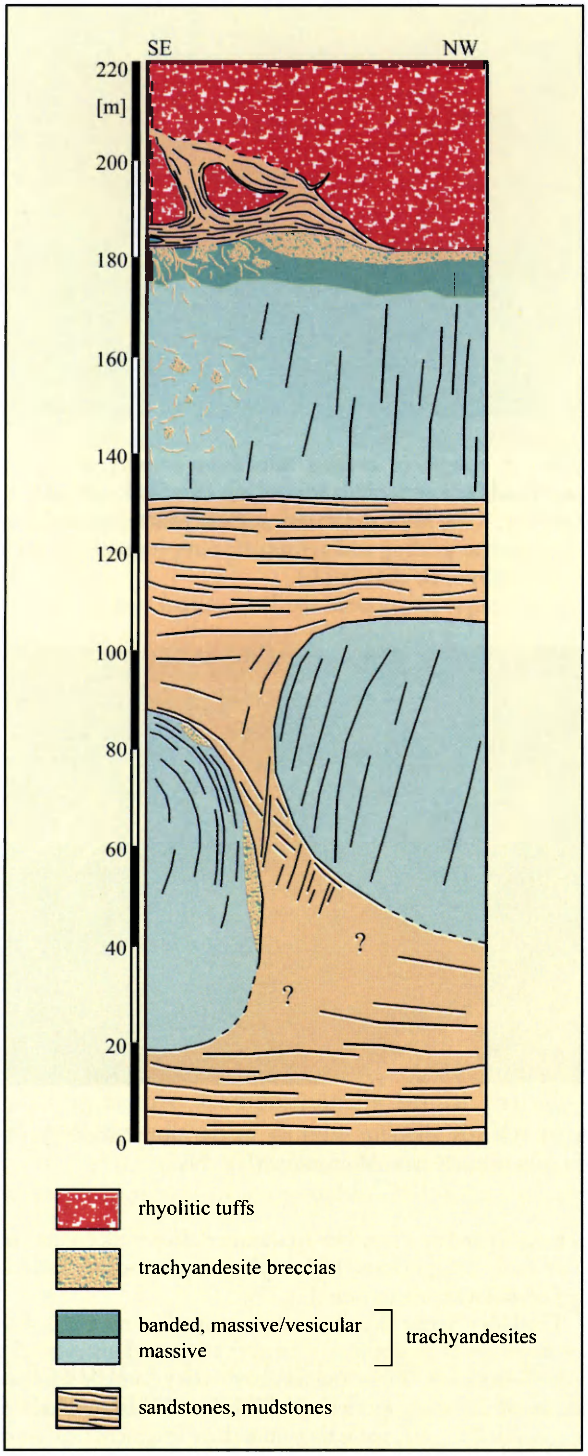

Fig. 31. A generalised section of the volcano-sedimentary sequence in the central part of the trachyandesite quarry near Gluszyca Górna (locality 21, Fig. 30). Details in the text.

canic rocks, including the rhyolitic tuffs, and proposed the opposite general emplacement sequence.

Based on the relationships characterised above, the Łomnica rhyolites and the Głuszyca trachyandesites are interpreted here as a complex of shallow level sills and laccoliths, emplaced after the deposition of the rhyolitic tuffs. The intrusive origin of the rhyolites is indicated by their lithological monotony, atypical of acidic lava flows or domes, which are invariably associated with a variety of volcaniclastic rocks (e.g. Cas & Wright, 1987; Howells *et al.*, 1991). The intrusive emplacement of the trachyandesites is well recorded at Głuszyca by the deformation of their country rocks, including the rhyolitic tuffs, the abundant trachyandesite breccias with sedimentary matrix, and the silification of the mudstones and siltstones.

The main feeders of the trachyandesitic and rhyolitic magmas were possibly located in the western part of this subvolcanic complex, near the southern prolongation of the Rusinowa–Grzmiąca zone. The trachyandesitic intrusions were emplaced after the rhyolites, and the geometry of the latter controlled the distribution of the former, resulting in the thickest accumulations of the trachyandesitic magma between the rhyolitic intrusions.

GÓRY SUCHE RHYOLITIC TUFFS (GSRT)

The Góry Suche rhyolitic tuffs form a nearly 50 km long outcrop, subparallel to the north-eastern margin of the Intra-Sudetic Basin, between Czarny Bór to the north-west and Suszyna to the south-east, at the top of the lower Permian volcanic complex (Fig. 4, 24 and 30). The tuffs dip south-westwards at low to moderate angles and attain their greatest thickness of c. 300 m in the middle part of their outcrop, near Hermankovice in the Czech Republic (Fediuk & Schovankova, 1979). South-eastwards, the tuffs gradually wedge out, and north-westwards thin down to less than 100 m adjacent to the fault zone west of Czarny Bór.

Near the villages of Radosna, Łomnica and Gluszyca (Fig. 30), the base of the tuffs is conformable and the underlying sedimentary sequence is intruded by trachyandesitic and rhyolitic sills and laccoliths (see above). Further west, however, between Grzędy and Sokolowsko (Fig. 24), the outcrop pattern, thickness variation and generally shallow dip of the tuffs indicate that the tuffs unconformably overlie an older, partly eroded volcanic centre – the Unislaw Śląski volcanic association. It is suggested that the palaeoslope of the older volcano was north-easterly inclined at a moderate angle (up to 20°), with c. 100 m deep, wide palaeovalleys marked by the thickest bedded tuff accumulations in the lower part of the Góry Suche rhyolitic tuffs. The thickness of the whole tuff sequence averages around 200 m, but in places (over basement highs ?) decreases down to c. 120 m (e.g. in the Nowe Siodlo bore-hole, Dathe *et al.*, 1910, vide Grocholski, 1973 b, p. 41).

The tuffs consist of, from bottom to top, three main lithologies (Fig. 32):

1) bedded tuffs (equivalent to the "rhyolitic tuffs and tuffites" of Grocholski, 1973 a, b),

2) massive, nonwelded tuffs (equivalent to the "rhyolitic vitroclastic tuffs" of Grocholski, 1973 a, b and Bossowski *et al.*, 1994, and the "rhyolitic tuffs" of Mastalerz *et al.*, 1995 a, b),

3) massive, welded tuffs (equivalent to the "rhyolitic ignimbrites" of Grocholski, 1973 a, b).

The bedded tuffs form a discontinuous layer of variable thickness between Grzędy and Sokolowsko and in the vicinity of Łomnica further east, where they were reported from pits (Kozlowski, 1958; Nożanka, 1958). The thickest accumulations of these deposits (over 100 m ?) occur north-west of Wysoka hill and north-east of Mieroszów. Around Wysoka hill (localities 23, 24 and 25) the tuffs usually consist of 1-5 cm thick laminae with variable structures, including subhorizontal lamination with reverse grain-size grading and bedding sags (Fig. 33) and, more

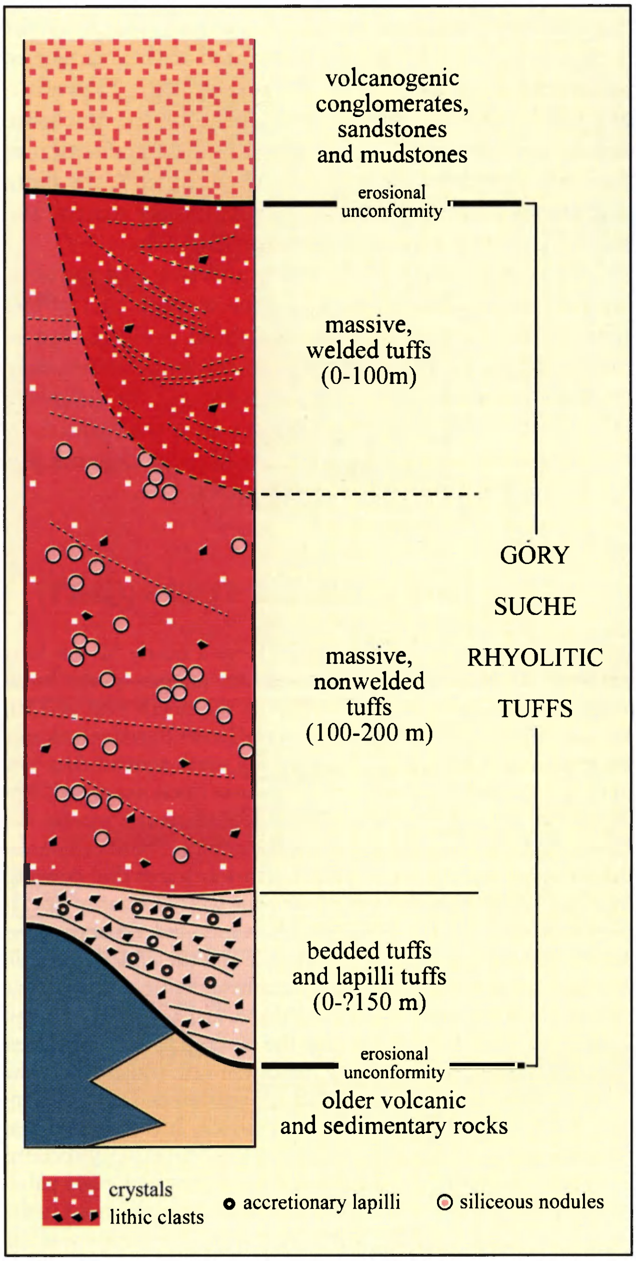

Fig. 32. A generalised log of the Góry Suche rhyolitic tuffs in the area between Grzędy and Mieroszów.

rarely, cross lamiantion. The grain size ranges from fine-grained tuff to lapilli tuff and the main components are devitrified glass shards, quartz and feldspar phenocrysts, lithic clasts and accretionary lapilli.

The massive, nonwelded tuffs constitute the main part of the sequence, are 100–200 m thick, and show the widest distribution. These tuffs are a monotonous sequence of red to pink coloured deposits characterised by indistinct layering (Fig. 34). They often show green reduction spots and a porous appearance, resulting from the weathering and leaching of less resistant components. Locally the tuffs contain abundant, oval concretions, 5 to 30 cm in size, enriched in chalcedony, clay minerals and carbonates relative to the host rock. The main components of the tuffs are devitrified glass shards and quartz and feldspar phenocrysts.

The massive nonwelded tuffs grade upwards into a discontinuous layer of massive, welded tuffs, up to several tens of metres thick. Compared with the other two lithologies, the welded tuffs are characterised by a lava-like appearance, deep pink colour, scarcity of lithic components, higher phenocryst content and platy joints of variable orientation (Fig. 35).

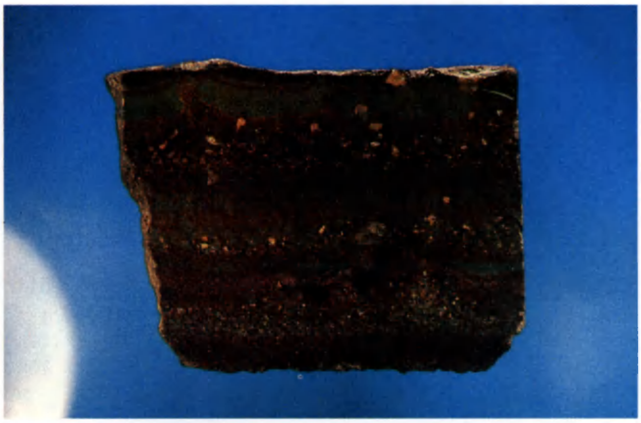

Fig. 33. A sample of bedded tuffs from locality 25 between Wysoka and Dzikowiec hills west of Unisław Śląski (Fig. 24). The sample is c. 7 cm high and shows subhorizontal lamination, reverse grain-size grading and asymmetric impact sags (the largest one with a rhyolitic clast inside).

Fig. 34. Gently dipping sheeting in the nonwelded rhyolitic tuffs at locality 26 near Mieroszów (Fig. 24).

The Góry Suche rhyolitic tuffs are overlain by a 200–400 m thick sequence of mudstones, siltstones and conglomerates of the Słupiec Formation. These sedimentary rocks contain significant amounts of volcanogenic detritus (Fediuk & Schovankova, 1979; Grocholski, 1973 b), including abundant fragments of welded tuffs, most probably derived from the underlying sequence. This feature, together with welding variation in a vertical section of the Góry Suche rhyolitic tuffs (see the discussion below) support earlier suggestions of an erosional unconformity at the top of the tuffs (Fediuk & Schovankova, 1979).

Interpretation. The Góry Suche rhyolitic tuffs are interpreted as a sequence of genetically related pyroclastic deposits, formed during a single explosive volcanic eruption. The structural and lithological variation of the tuffs in vertical section reflects changing eruptive and depositional mechanisms of the pyroclastic material, as well as post-depositional modification of the tuffs due to welding, devitrification and recrystallization. The bedded tuffs at

Fig. 35. Platy joints in the welded tuffs in an abandoned quarry near Grzędy (locality 22, Fig. 24).

the base of the sequence show structures typical of pyroclastic surge and fall deposits. A dominant role of pyroclastic surges is suggested by the lateral thickness variation of these tuffs, which possibly reflects enchanced accumulation within palaeovalleys. A phreatomagmatic eruption mechanism is indicated by accretionary lapilli and bedding sags within the deposits. The overlying massive tuffs represent an ash-flow deposit (an ignimbrite). Its homogeneous structure suggests that it is a single flow unit, deposited from one major pyroclastic flow. The indistinct platy joints of the tuffs might have originated due to an internal shearing within the flow body at the waning stages of its emplacement. The welding of the tuffs indicates a high emplacement temperature, and a magmatic eruption mechanism. However, the upward increase of welding, with the most strongly welded tuffs at the top of the ignimbrite, is a striking feature. Compositionally similar rhyolitic ignimbrites typically show densest welding in their central to lower parts which retain high temperature the longest after deposition and are subjected to the load of the overlying deposit (Fisher & Schmincke, 1984; Cas & Wright, 1987). The peculiar welding variation of the considered ignimbrite sheet, together with abundant welded ignimbrite fragments within the overlying clastic sequence point to a significant erosion of the ignimbrite in Permian times, before the deposition of the overlying clastic deposits. It is possible that nearly half of the original thickness of the ignimbrite sheet could have been eroded.

The variation of depositional and eruptive mechanisms of the Góry Suche rhyolitic tuffs fits a general sequence of events that might be expected during a progressive tapping of a shallow level silicic magma chamber during an explosive, Plinian-type, ignimbrite-forming volcanic eruption (Fisher & Schmincke, 1984; Cas & Wright, 1987; Howells *et al.*, 1991). The bedded tuffs at the base of GSRT can be related to an initial, phreatomagmatic stage of the eruption and deposition from a low, cool and pulsating eruption column, and the overlying ignimbrite can have originated due to a major collapse of a higher, dense and hot eruption column, formed at the main, magmatic stage of the eruption.

The problem of the eruption centre location of the Góry Suche rhyolitic tuffs has not been definitely solved. The location of the vents SW of Unisław Śląski suggested by Grocholski (1973 a, b) is not consistent with the geological relationships discussed above. However, explosive eruptions and intrusions of chemically and petrographically equivalent magmas (the Rusinowa–Grzmiąca rhyolites) occurred in late Carboniferous times along the eastern margin of the Wałbrzych Basin. A welded-tuff filled plug exposed near the southern end of the Rusinowa–Grzmiąca belt cuts the older tuffs and rhyolites, has no equivalents within the Carboniferous sequence and could have represented one of the active vents of the Góry Suche rhyolitic tuff eruption. The main eruption site is possibly marked by a caldera, 10 km in diameter, located at a southward prolongation of the Rusinowa–Grzmiąca belt, between Nowa Ruda and Broumov, south-east of the area of the present study (Awdankiewicz, 1998).

SUMMARY

CLASSIFICATION, DISTRIBUTION AND SUBDIVISION OF THE VOLCANIC ROCKS

New data on the geology and geochemistry of the Carboniferous–Permian volcanic rocks of northern part of the Intra-Sudetic Basin have shown that the earlier classifications, subdivisions and correlations are largely unreliable. The revised classifications (Fig. 3) and distribution of various lithologies (Fig. 4) were the basis for the subdivision of the volcanic succession into three complexes and several smaller units (Fig. 5). These subdivisions provided a framework for more detailed descriptions of the volcanic rocks, including discussion and interpretation of their geological forms, emplacement modes and eruption sites. Based on these results, the location of the volcanic centres and the sequence of volcanic events can be reconstructed.

THE VOLCANIC CENTRES AND THE SEQUENCE OF EVENTS

The volcanic complexes in the northern part of the Intra-Sudetic Basin (Fig. 4) reflect three episodes of volcanic activity: during the early Carboniferous, late Carboniferous and early Permian. Within the complexes, the associations are interpreted as the main centres of volcanic and/or subvolcanic activity. These volcanic centres were composite and consisted of several vents or smaller volcanoes. The lithological units within the associations represent the products of successive stages of volcanic activity. Each volcanic centre was characterised by a specific development with respect to magma types and their mode and sequence of emplacement. The distribution of pyroclastic rocks, lavas and subvolcanic intrusions together with the

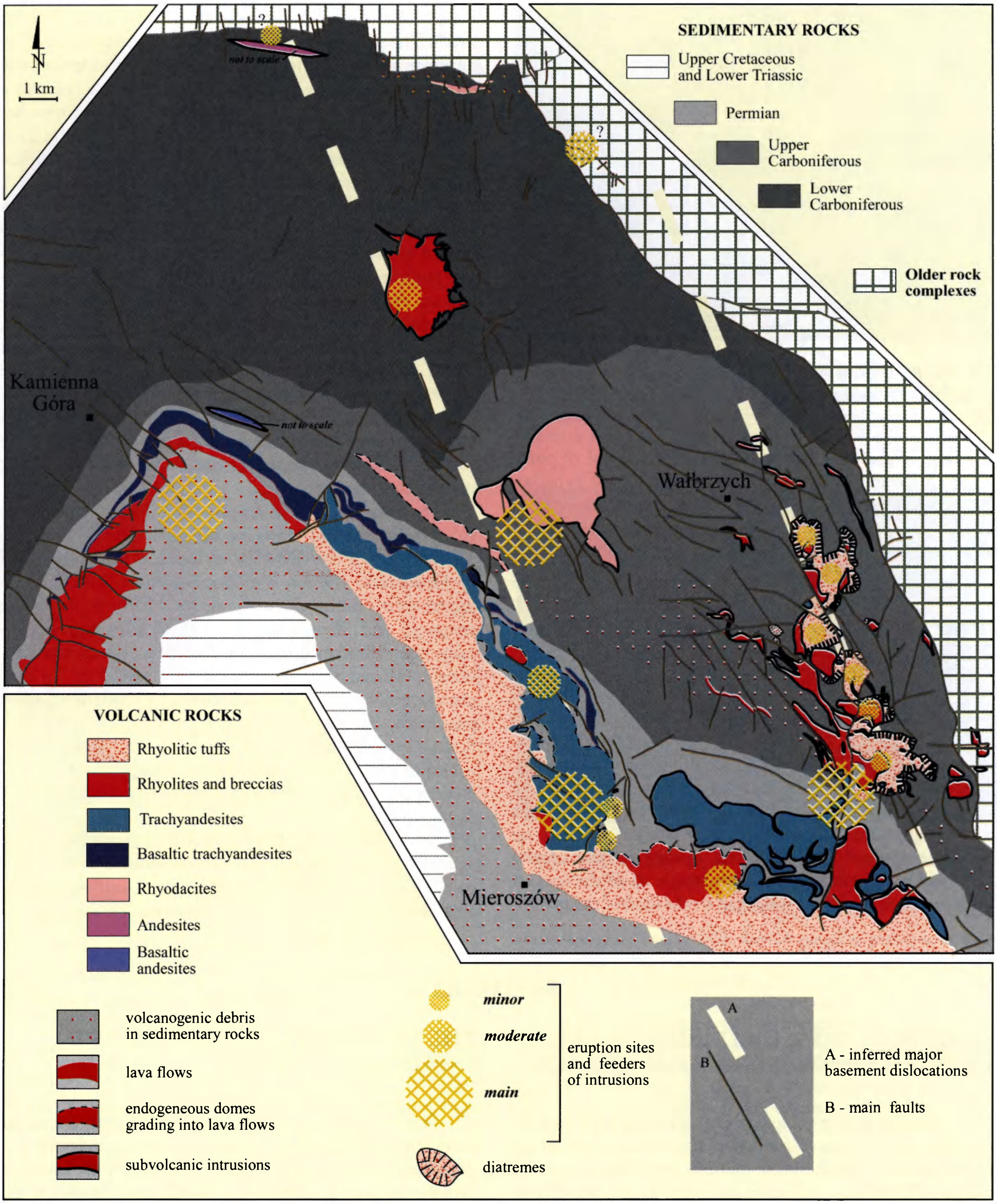

Fig. 36. Interpretative geological sketch of northern part of the Intra-Sudetic basin showing the distribution of pyroclastic rocks, lavas and subvolcanic intrusions together with the probable location of their eruption sites. Comments in the text.

probable location of their eruption sites is shown in Fig. 36.

The lower Carboniferous volcanic complex reflects the earliest volcanic activity in the Intra-Sudetic Basin, associated with its opening in late Tournaisian/early Visean times. A silicic volcanic centre located near the northern-eastern edge of the basin erupted rhyodacitic lavas with subordinate tuffs (the Stare Bogaczowice rhyodacites).

Further west, thin andesite sills (the Nagórnik andesites), possibly fed from vents near the northern basin margin, intruded the sedimentary sequence.

The upper Carboniferous volcanic complex formed during the next volcanic phase in late Westphalian-Stephanian times. Volcanic centres were located along the western and eastern margins of the Walbrzych Basin, a major late Carboniferous depositional centre in the area. The western Walbrzych Basin volcanic association represents an acidic eruptive centre, composed of laccoliths, dykes and lava domes (the Chelmiec rhyodacites, Stary Lesieniec rhyodacites and Trójgarb rhyolites), with thin basaltic andesite sills further west (the Borówno basaltic andesites). The eastern Walbrzych Basin volcanic association is a linear belt of diatremes with associated plugs, dykes and sills, largely of acidic composition (the Rusinowa–Grzmiąca rhyolites), with less abundant intermediate rocks (the Rusinowa–Grzmiąca trachyandesites). The diatremes represent the roots of maar-type volcanoes. The activity commenced with explosive, phreatomagmatic eruptions of rhyolitic magmas. Accumulation of pyroclastic deposits was followed by their subsidence within the diatremes, with the emplacement of rhyolitic and trachyandesitic intrusions.

The lower Permian volcanic complex formed at the climax of volcanic activity in the area. This phase of volcanism commenced in the western part of the Intra-Sudetic Basin where the main eruptive centre was the Góry Krucze volcanic association. The association consists of a small shield volcano formed by effusions of basic lavas to the north (the Kamienna Góra basaltic trachyandesites), and an extensive cover of rhyolitic lavas (the Góry Krucze rhyolites) erupted from vents to the south, beyond the study area (Awdankiewicz *et al.*, 1998). A similar sequence of events is characteristic of the Unislaw Śląski volcanic association, a composite volcano in the central part of the Intra-Sudetic Basin. There, the emplacement of basic lavas and sills from several scattered vents (the Lesieniec-Sokołowsko basaltic trachyandesites) was followed by intermediate and acidic extrusions (the Stożek Wielki trachyandesites, and the Dzikowiec, Lugowina and Waligóra rhyolites), and an extensive trachyandesitic flow (the Grzędy trachyandesites) was emplaced down the western slopes of the volcano.

During the next eruptive event of the Permian volcanic phase, a widespread, tens to hundreds metres thick cover of the Góry Suche rhyolitic tuffs was deposited across the Intra-Sudetic Basin. The main eruption site is possibly marked by a 10 km in diameter caldera located SE of the study area (Awdankiewicz, 1998). The tuffs originated during a large, Plinian-type explosive eruption. The bedded tuffs at the base of the sequence are pyroclastic fall and surge deposits related to initial, phreatomagmatic stages of the eruption, and the overlying massive tuffs represent a partly welded an ignimbrite formed at the main phase of the eruption.

The Rybnica Leśna volcanic association reflects the youngest igneous event in the study area. The association consists of acidic and intermediate sills and laccoliths (the Lomnica rhyolites, Bukowiec and Gluszyca trachyandesites) that intruded the Permian sequence after the deposition of the Góry Suche rhyolitic tuffs. The feeders of the intrusions were located along the southern prolongation of the Rusinowa–Grzmiąca zone, close to the northern margin of the caldera mentioned above.

The geochemical and petrographic characteristics of the Carboniferous and Permian volcanic rocks changed at successive stages of volcanism. Rhyodacites with associated andesites and basaltic andesites were characteristic of the earlier stages of volcanism (early and late Carboniferous), while basaltic trachyandesites, trachyandesites and rhyolites erupted at the later stages (late Carboniferous and Permian). A strong lateral variation is also observed, with the least evolved rocks (andesites in the early Carboniferous, basaltic andesites in the late Carboniferous and basaltic trachyandesites in the Permian) erupted mainly from vents to the west, and the intermediate-acidic compositions more abundant in the east. The eruptions of less evolved rocks in the western part of the basin were largely effusive, while the main explosive events were related to acidic magmas in the eastern part of the basin. These variations most probably reflect processes at mantle and deep crustal-levels, including differentiation in magma chambers, and these problems will be addressed in a separate paper.

TECTONISM, VOLCANISM AND SEDIMENTATION

The data on the location and development of the volcanic centres summarised above allow preliminary assessments on the interrelationships between tectonism, volcanism and sedimentation to be made. The distribution of the successively active volcanic centres strongly suggest that: 1) the volcanic activity migrated south-eastwards, consistently with the intrabasinal depositional centres, and 2) the contemporaneous active fault zones that influenced the depositional processes controlled also the location of volcanic centres. These relationships are most clear in the NE part of the Intra-Sudetic Basin. There, the early Carboniferous, late Carboniferous and Permian volcanic centres are arranged in two NNW–SSE trending belts, possibly controlled by faults within the basement, with the oldest volcanic centres to the NNW and the youngest ones to the SSE. The western belt comprise the Nagórnik andesites, western Walbrzych Basin volcanic association and Unislaw Śląski volcanic association, and the eastern belt comprises the Stare Bogaczowice rhyodacites, eastern Walbrzych Basin volcanic association and Rybnica Leśna volcanic association. The south-eastward migration of volcanic activity in Permian times is indicated by the development of the oldest Permian volcanoes in the western-central part of the Intra-Sudetic Basin (the Góry Krucze and Unislaw Śląski volcanic associations), followed by the activity further to the east and south-east (the Góry Suche rhyolitic tuffs and Rybnica Leśna volcanic association), and then in the south-easternmost part of the basin near Broumov and Suszyna (Nowakowski, 1968; Madej, 1998).

The emplacement modes of the volcanic rocks were strongly influenced by the location of the volcanoes relative to the intrabasinal depositional centres and the related lateral thickness variation of the contemporaneous sedimentary rocks. A westward gradation from subvolcanic intrusions, through transitional, endogenous/exogenous domes, into lava domes and flows, observed within the western Wałbrzych Basin volcanic association and the lower Permian volcanic complex, coincides with a general westward thickness decrease of upper Carboniferous and lower Permian sedimentary rocks. Similarly, in the eastern Wałbrzych Basin volcanic association rhyolitic dykes and sills are more abundant on the Wałbrzych Basin side of the volcanic belt, where the late Carbonifeorus deposits are thicker. These correlations possibly reflect density gradient control on the buoyancy-driven rise of magmas towards the Earth's surface: thicker accumulations of young, low-density sediments formed density barriers that trapped the magmas as subvolcanic intrusions, while thinner sedimentary covers allowed the melts to reach the Earth's surface.

On the other hand, the volcanic activity also affected sedimentation. The main volcanic centres identified in this study (the western and eastern Wałbrzych basin volcanic associations, and the Góry Krucze and Unisław Śląski volcanic associations) correspond well with intrabasinal elevations inferred from geological and sedimentological studies (Dziedzic, 1961; Grocholski, 1965; Nemec, 1981 b; Bossowski & Ihnatowicz, 1994 a, b; Mastalerz, 1996 b). Erosion of these volcanic centres supplied the surrounding basins with volcanogenic detritus, which is most abundant within the Stare Bogaczowice, Glinik and Słupiec Formations (Fig. 36), contemporaneous with or immediately following the main phases of volcanism (Teisseyre, 1970 a; Grocholski, 1965; Fediuk & Schovankova, 1979; Tasler & Prouza, 1979). The largest input of volcanic clasts in Permian times postdated the most voluminous acidic eruptions of the Góry Krucze rhyolites and the Góry Suche rhyolitic tuffs. The eruption of the latter created a caldera that became a lacustrine depositional centre (Awdankiewicz, 1998).

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