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THE LOWER PALEOZOIC VOLCANICLASTIC ROCKS FROM THE EASTERNMOST PART OF THE BOLKÓW UNIT (GÓRY KACZAWSKIE MTS., SW POLAND): THEIR ORIGIN AND MODE OF DEPOSITION

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Abstract: Lower Paleozoic metamorphosed greenschist facies volcaniclastic rocks with well preserved primary structures occur in the eastern part of the Bolków unit, within the Kaczawa complex, West Sudetes. They are interpreted mostly as deposits of turbulent gravity flows ranging from high concentration flows to dilute turbidity currents, with subordinate ash-flow tuffs. These rocks are considered to have been deposited in a relatively deep marine environment, close to active volcanic centres.

Key words: volcaniclastic rocks, gravity flows, turbidites, ash-flow tuffs, Góry Kaczawskie, Sudetes.

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INTRODUCTION

The Góry Kaczawskie Mts. area, West Sudetes, comprises a large outcrop of the Paleozoic basement rocks. The primary character of those rocks has been partly obscured by greenschist facies metamorphic overprint. Volcanogenic rocks cropping out near Jeżów and Gorzanowice, NW and N of Bolków, in the eastern part of the Bolków unit (Fig. 1), have been known as "schistose greenstones" (Teisseyre, 1976, 1977) and interpreted as "tuffaceous", "breccial" or "agglomeratic" rocks (Zimmermann & Haack, 1929, 1935; Turnau-Morawska, 1953, vide Teisseyre *et al.*, 1957). In this paper primary depositional features recognized in these rocks are described and their possible origin and mode of deposition are considered.

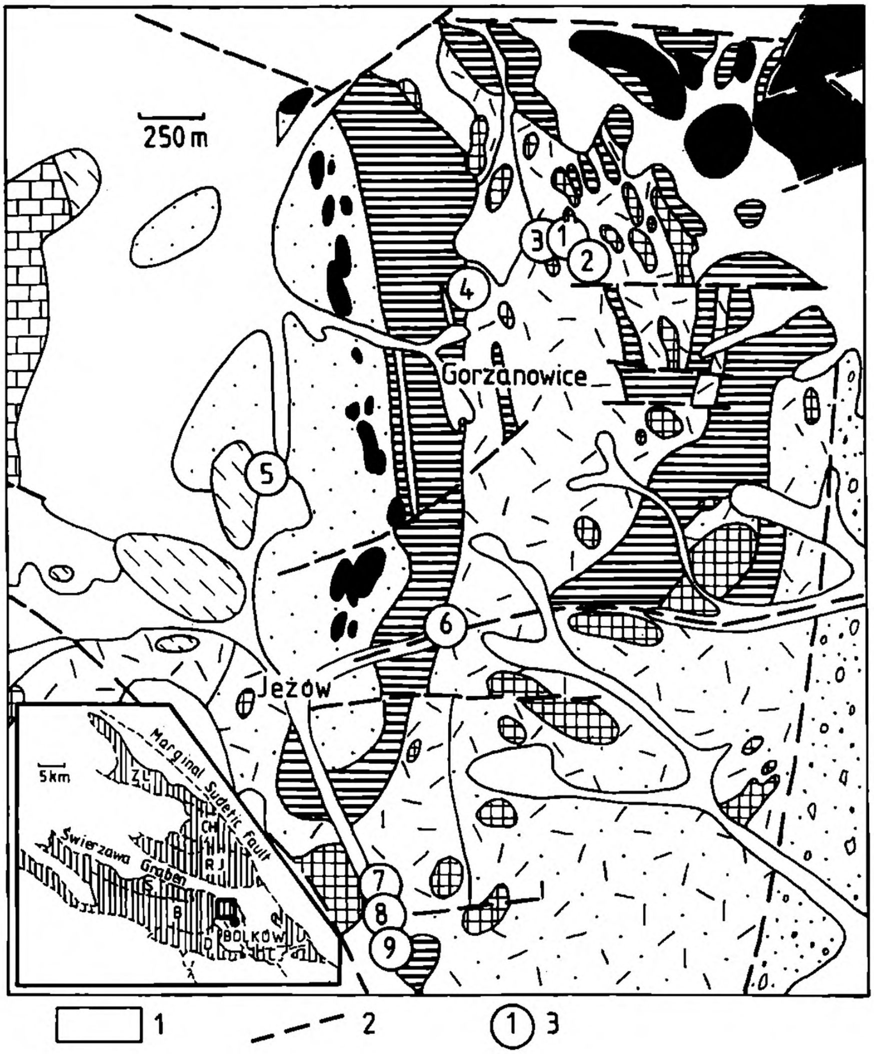
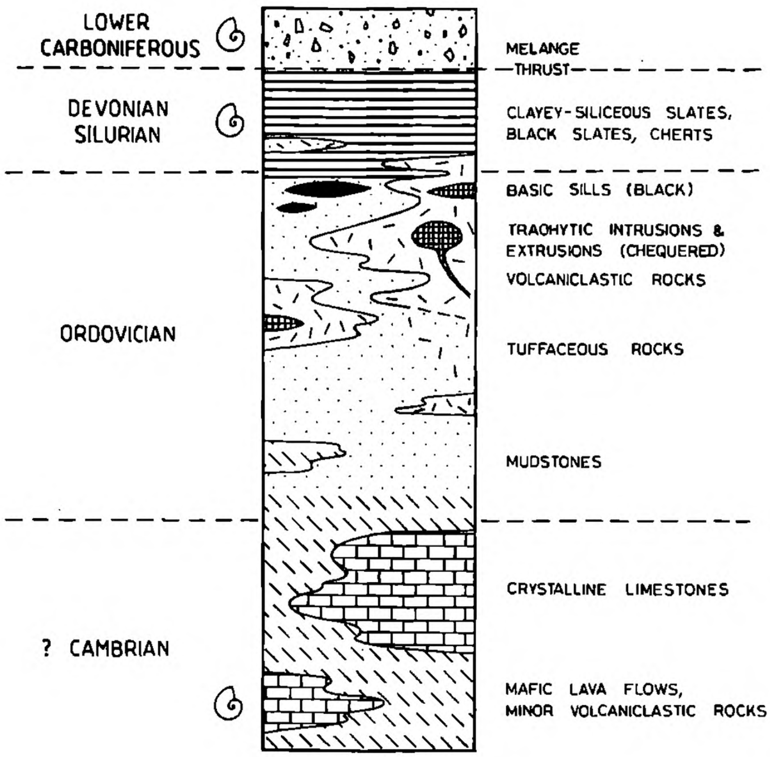


Fig. 1 Geological map of the area N and NW of Bolków (based on unpublished materials of R. Kryza and A. Muszyński and Awdankiewicz, 1989). Symbols of metamorphic rocks as in Fig. 2. Other symbols: *1* – post-Variscan cover and Quaternary, *2* – faults and thrusts, *3* – localities. Inset: sketch to locate the study area (rectangle) in the Góry Kaczawskie Mts. Dashed are Paleozoic metamorphic rocks. Tectonic units of the Góry Kaczawskie according to Teisseyre (1967): *ZL* – Złotoryja-Luboradz, *CH* – Chełmiec, *RJ* – Rzeszówek-Jakuszowa, *S* – Świerzawa, *B* – Bolków, *D* – Dobromierz, *C* – Cieszów.

GEOLOGICAL SETTING

The southern part of the Góry Kaczawskie Mts. comprises four tectonic units (Fig. 1), which are interpreted as south-verging nappes (Teisseyre, 1963, 1967) or thrust sheets (Baranowski *et al.*, 1987; Furnes *et al.*, 1989). The Bolków unit which we are dealing with, is built of sedimentary and volcanic rocks of Cambrian(?) to Early Carboniferous age (Baranowski *et al.*, 1987; Haydukiewicz, 1987; Furnes *et al.*, 1989). A schematic lithostratigraphic

Fig. 2 Schematic lithostratigraphic column of the eastern part of the Bolków unit (based on Haydukiewicz, 1987, modified). 'Molluscs' indicates the presence of fossils



profile of the eastern part of this unit is shown in Fig. 2. The volcaniclastic rocks are underlain and interfingered with Ordovician mudstones of probably turbiditic origin, and are overlain by pelagic pelitic rocks (clayey-silicious slates, black slates, cherts), locally containing Silurian graptolites and Devonian conodonts (Haydukiewicz & Urbanek, 1986; Haydukiewicz, 1987; Baranowski *et al.*, 1987). Basic sills are common at the top of the mudstone sequence, and trachytic (keratophyric) shallow intrusions or lava flows are associated with the volcaniclastic rocks. The basic and acid volcanic rocks are part of a bimodal alkaline suite which occurs also in other parts of the Góry Kaczawskie Mts. (Kryza *et al.*, 1989).

VOLCANICLASTIC ROCKS

CLASSIFICATION AND DISTRIBUTION OF LITHOLOGIES

In the easternmost part of the Bolków unit the volcaniclastic rocks have been classified into three groups distinguished with respect to their constituents, textures and sedimentary strutures (Table 1). Two of the groups, the polylithologic and monolithologic volcaniclastic rocks were subdivided, according to Fisher's non-genetic textural classification (1961, vide Suthren 1985), into conglomerates, sandstones, siltstones and mudstones. The third group, the crystal-rich volcaniclastic rocks is represented by sandstones only.

Table 1

Classification of volcaniclastic rocks from the easternmost part of the Bolków unit

LITHOLOGY		GROUP OF ROCKS: POLYLITHOLOGIC VOLCANICLASTIC ROCKS	GROUP OF ROCKS: MONOLITHOLOGIC VOLCANICLASTTIC ROCKS	GROUP OF ROCKS: CRYSTAL-RICH VOLCANICLASTIC ROCKS
CONSTITUENTS		diverse set of lithic clasts	uniform set of lithic clasts	crystals
TEXTURE	grainsize	up to 35 cm	up to 15 cm	up to 0.5 mm
TEXTURE	shape of clasts	angular or ellipsoidal	usually highly flattened	anhedral to subhedral
TEXTURE	fabric	usually compact, open framework in coarse conglomerates	compact	compact
STRUCTURES	thickness of beds	up to 2 m	? up to several meters	not known
STRUCTURES	grading	reverse and normal	? lack or normal	lack
STRUCTURES	lamination	subhorizontal and cross	lack	lack

The polylithologic volcaniclastc rocks are exposed mainly in the northern part of the study area (Fig. 1: localities 1, 2, 3 and 5) and the monolithologic varieties prevail in the southern part (Fig. 1: localities 6-9). The finer-grained volcaniclastic rocks, especially the polylithologic volcanic sandstones, mudstones and siltstones, predominate. The crystal-rich volcaniclastic rocks were only observed in locality 4.

POLYLITHOLOGIC VOLCANICLASTIC ROCKS

Lithologies and sedimentary structures

The polylithologic volcaniclastic rocks are dark-green or purple in colour. They mainly comprise volcanic sandstones, mudstones and siltstones but locally include coarse- to fine-grained volcanic conglomerates. The coarser-grained conglomerates are very massive with an open framework and clasts up to 35 × 15 cm large. The fine-grained conglomerates, sandstones, mud-

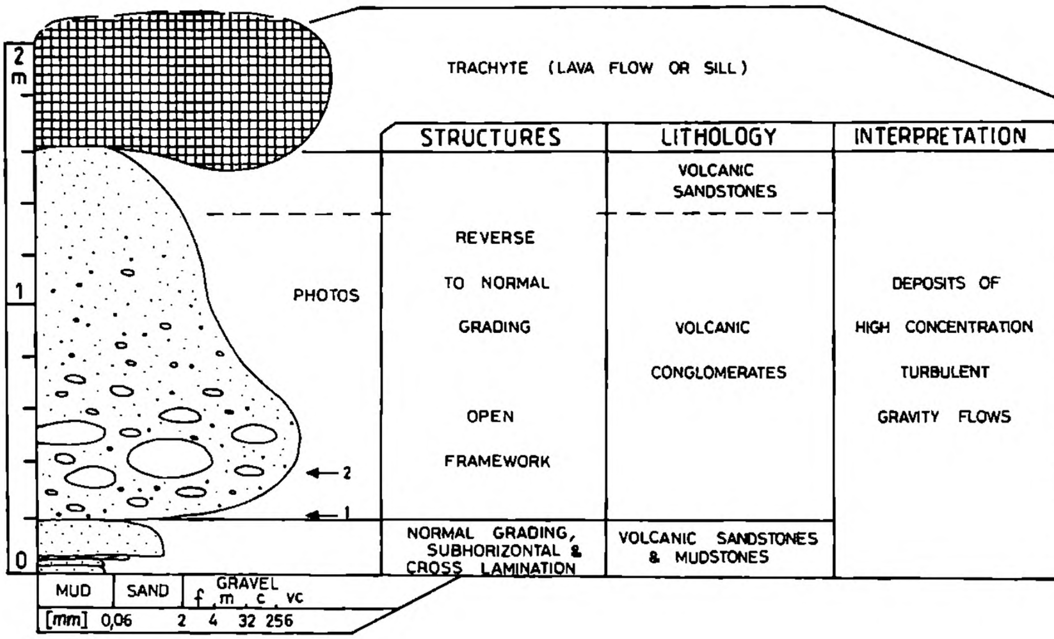


Fig. 3 Schematic log and interpretation of the sequence at locality 1. Number of photos refer to Plate I

stones and siltstones are laminated with a compact fabric and are cut by a cleavage oblique to the lamination.

In locality 1, coarse- to fine-grained polylithologic volcaniclastic rocks underlie a trachyte sill or lava flow (Fig. 3). The lowermost part of the profile comprises about 20 cm thick layer of graded and laminated volcanic sandstones and mudstones They are overlain by a reverse to normally graded, 1.5 m thick bed of matrix-supported volcanic conglomerate (Pl. I: 1, 2), which passes upwards into volcanic sandstone.

In locality 2 a folded sequence of polylithologic volcaniclastic rocks with subordinate intercalations of non-volcanogenic mudstones is exposed. The profile in the best exposed part (Fig. 4) starts with greenish-grey mudstones composed of quartz-rich, up to 5 mm thick, and white mica-rich, up to 2 mm thick, laminae. Above, approximately 2 m thick, amalgamated beds of matrix-supported, coarse- to fine-grained volcanic conglomerates, showing good to poor normal grading, occur. These grade into interlayering volcanic fine-grained conglomerates, sandstones, mudstones and siltstones which consist of normally or reverse to normally graded, and cross- or subhorizontally laminated, few cm thick layers (Pl. I: 3, 4; Fig. 5a, b). The muddy and silty laminae are dark-red, hematite-rich, and locally discontinuous. Bioturbations are present within the finest-grained laminae. These lithologies grade into the non-volcanogenic mudstones again.

A similar, subhorizontally laminated, dark-red, muddy and silty lithology occurs in locality 3 where it forms interbeds up to 10 cm thick within light grey and greenish cherts.

Constituents and mineral composition

In the coarser-grained lithologies, lithic clasts are the main constituent. Most of the clasts belong to one of the following two rock types.

(1) cream-coloured acid volcanic rocks, moderately vesicular, with aphanitic, aphyric and felsitic textures. These are composed of anhedral quartz, anhedral to subhedral lath-shaped albite and small flakes of white mica. Round, quartz-filled vesicles, up to 5 mm in diameter, tend to be concentrated within the inner part of clasts. In locality 1 clasts of the gravel fraction reveal a decrease of the crystal size and an increase of the white mica content towards their margins (Pl. II: 1). These features may reflect rapid chilling. The texture and composition of the most abundant smaller clasts (of the sand-sized fraction) closely resemble the marginal parts of the larger clasts.

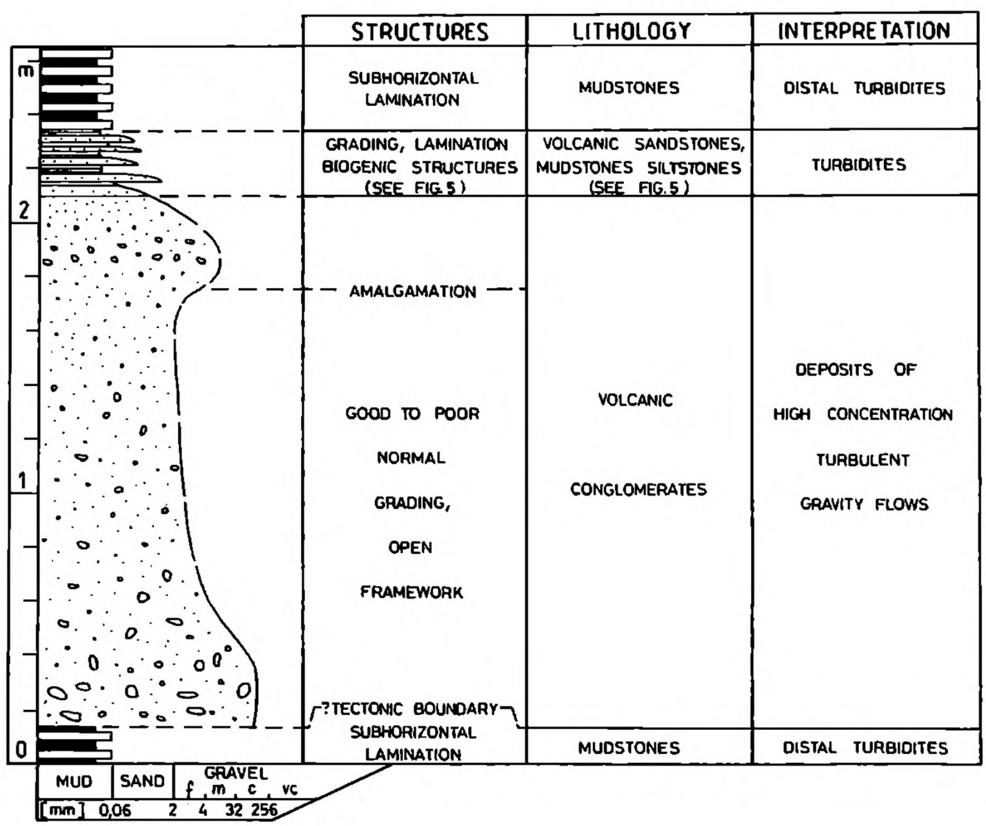


Fig.4 Schematic log and interpretation of the sequence at locality 2

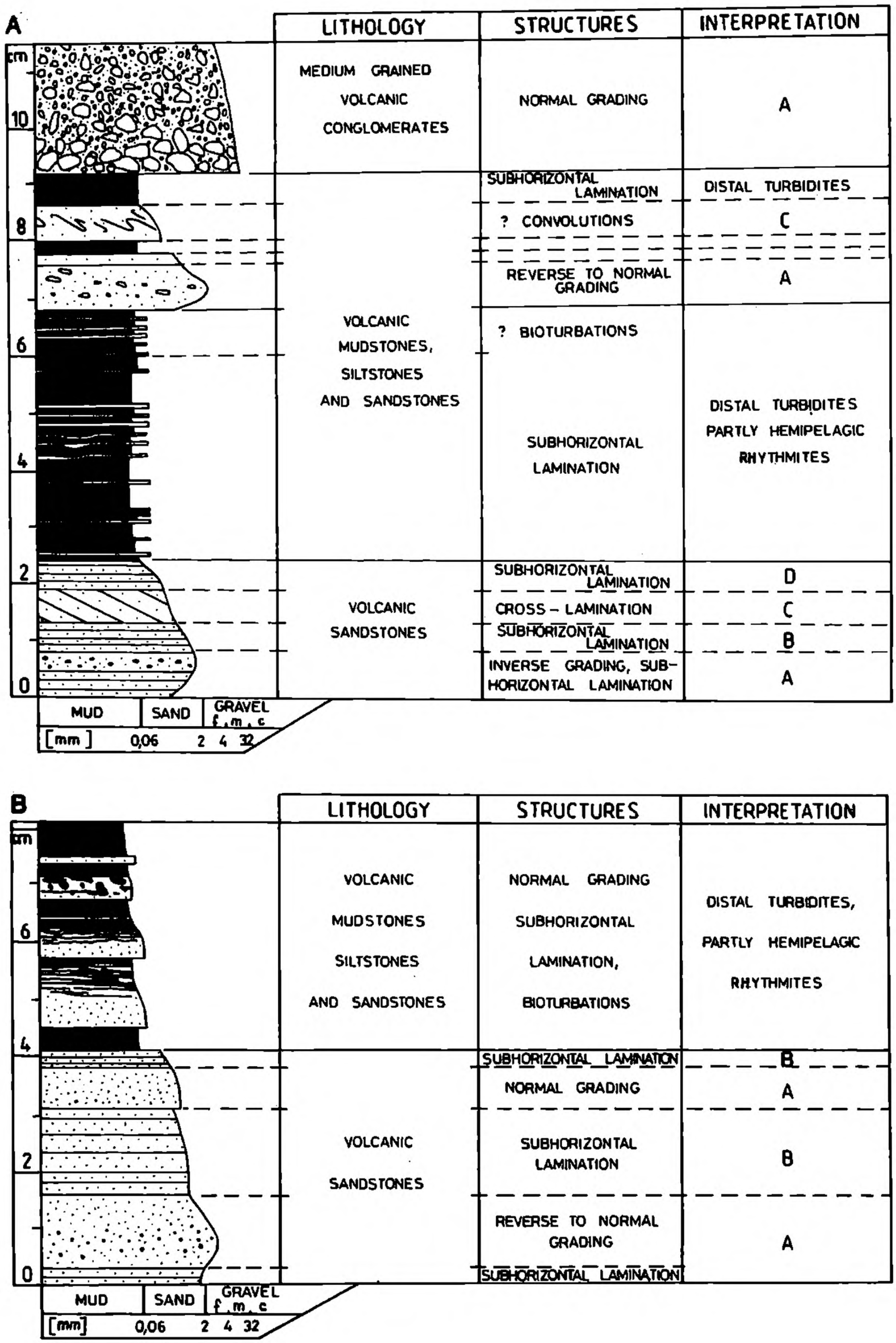


Fig. 5 Sedimentary structures of turbidites at locality 2. Fig. 5a shows sample 3, Pl. I: 3

(2) Dark grey or black, intermediate to basic volcanic rocks composed of quartz-albite-white mica pseudomorphs after lath-shaped feldspars, up to 0.3 mm long, set in a groundmass of opaque minerals, white mica and quartz. The texture of these rocks is massive or trachytic (Pl. II: 2).

In addition, volcaniclastic rocks at locality 2 contain clasts of laminated volcanic sandstones and mudstones.

Most of the fragments are angular to subangular. In locality 1, however, ellipsoidal clasts of acid volcanic rocks with chilled margins are abundant. Some smaller clasts are sheared along the cleavage planes but, generally, the primary shape of clasts does not seem to bear significant tectonic overprint.

The fine-grained, mud and silt lithologies are composed mainly of small flakes of white mica and opaque minerals (these minerals are also abundant in the finest fraction of the matrix in conglomerates). Some laminae also contain elongated, subhedral aegirine crystals, up to 0.1 mm long, partly altered into a dark or opaque aggregate. The XRD analysis of these laminae showed also the presence of muscovite, alkali feldspar and hematite. In locality 3, numerous angular quartz grains, up to 0.1 mm, and oval-shaped aggregates of white mica and chlorite occur.

MONOLITHOLOGIC VOLCANICLASTIC ROCKS

The monolithologic volcaniclastic rocks are greenish or dark-grey to black in colour and slightly porous in places. They comprise mainly volcanic sandstones, mudstones and siltstones with some medium-grained volcanic conglomerates. The fabric is usually compact but sorting is rather poor. All these rocks have a good, bedding-parallel foliation cut by an oblique cleavage. The clasts are highly flattened paralell to the foliation. The lineation is marked by tiny folds and, in places, by elongated clasts.

The monolithologic volcaniclastic rocks are composed of mica aggregates (clasts) enclosed in a micaceous matrix containing 20-60 vol. % of opaque minerals. In all samples, the clasts have nearly the same composition and texture. The micas form very small flakes. White mica is most common, but locally chlorite, green biotite or stilpnomelane are also abundant. Albite, apatite and quartz are rare. In some rocks rich in stilpnomelane, a blue amphibole of the riebeckite-glaucophane group occurs. It forms short, isolated crystals or radial aggregates, particularly inside the lensoid quartz concentrations.

The most abundantly occurring lithologies, the monolithologic volcanic sandstones and siltstones, consist of clasts less than 2 mm in size, set in a finer grained, opaque-rich matrix (Pl. II: 3). The fragmental texture is obvious in sandy lithologies, whereas only small, isolated clasts can be distinguihed in the silty rocks. At locality 7, these rocks contain also rare, highly vesicular, angular fragments, up to 15 cm in size (pumice ?). In places (localities 6 and 7), the volcanic siltstones are chlorite- and quartz-rich. The chlorite is concentrated in pressure shadows adjacent to quartz aggregates, which results in characteristic dark-green spots which are distinctive on the foliation planes.

At locality 9, a monolithologic medium-grained volcanic conglomerate is composed of moderately well packed clasts, up to 20 mm long (Pl. II: 4). The clasts consist of small white mica flakes and grains of opaque minerals. The matrix is composed of fine grained aggregate of white mica with rare albite, apatite and quartz.

The monolithologic volcaniclastic rocks form rather thick massive beds of usually uniform character. However, in locality 8, a gradation from volcanic sandstones to volcanic siltstones within an interval of 30 cm may represent primary normal grading. No other sedimentary structures have been observed.

CRYSTAL-RICH VOLCANICLASTIC ROCKS

These rocks, exposed at locality 4, are greenish-grey in colour, massive and fine grained (grains up to 0.2 mm). The two main components (about 50 vol. %) are white mica and green, partly chloritized biotite with about 40 % of quartz and albite. The latter is often chessboard twinned and partly replaced by white mica. Some opaque minerals form rectangular or skeletal crystals. The anisometric grains, flakes and thin, irregular layers of micas are oriented subparalell to the moderately defined cleavage planes. Sedimentary structures have not been observed.

INTERPRETATION

The overall character of this volcano-sedimentary rock sequence points to its origin in a marine environment. The inferred mode of deposition of the polylithologic volcaniclastic rocks (see below), and the mostly fine-grained character of the associated non-volcanic sedimentary rocks, suggest relatively deep-marine conditions of accumulation. The close association of the volcaniclastic rocks with numerous trachyte bodies may indicate proximity to active volcanic centres.

The bedding style of the polylithologic volcaniclastic rocks indicates deposition by turbulent gravity flows, ranging from high concentration flows (conglomerates with open framework) to normal and dilute turbidity currents (fine grained conglomerates with compact fabric and sandstones, mudstones and siltstones). In addition, multiple interlaminations of sand and mud may have been laid down within single autocyclic depositional events (Stow & Bowen, 1978). The wide lithological variation of the constituents suggests an epiclastic origin (sensu Fisher & Schmincke, 1984) for these rocks. However, some of the fragments (blocks of acid lavas with chilled margins) may represent pyroclastic material.

The interpretation of the other rocks described is more problematic due to the lack of distinct sedimentary structures. The monolithologic volcaniclastic rocks may represent ash-flow tuffs. This is suggested by (1) their composition, which may have resulted from the alteration of originally volcanic glass-rich deposits, (2) the massive and thick appearance of the beds and (3) the texture resembling, in places, the eutaxitic texture of welded ash-flow tuffs (however, the flattening of the clasts may be due to tectonic processes).

The crystal-rich volcaniclastic rocks are compositionally and texturally similar to pyroclastic rocks and may represent altered pyroclastic flow deposits.

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Streszczenie

DOLNOPALEOZOICZNE SKAŁY WULKANOKLASTYCZNE ZE WSCHODNIEJ CZĘŚCI JEDNOSTKI BOLKOWA (GÓRY KACZAWSKIE): ICH GENEZA I MECHANIZM DEPOZYCJI

Marek Awdankiewicz

W pracy przedstawiona jest charakterystyka petrograficzna i sedymentologiczna dolnopaleozoicznych, zmetamorfizowanych w facji zieleńcowej skał wulkanoklastycznych występujących we wschodniej części jednostki Bolkowa w Górach Kaczawskich. Skały te reprezentują osady stosunkowo głębokiego zbiornika morskiego, sąsiadującego z aktywnymi centrami wulkanicznymi. Obserwowane w skałach wulkanoklastycznych struktury sedymentacyjne pozwalają interpretować je jako osady turbulentnych spływów grawitacyjnych oraz potoków piroklastycznych.

Obszar objęty badaniami położony jest w Górach Kaczawskich, we wschodniej części jednostki Bolkowa (Fig. 1). Przedmiotem badań były zmetamorfizowane w warunkach facji zieleńcowej skały wulkanoklastyczne, określane dotychczas jako "złupkowane zieleńce" lub "łupki zieleńcowe", interpretowane ogólnie jako "tufity", "brekcje" lub "aglomeraty". Na NW od Bolkowa skały te są podścielone przez ordowickie(?) mułowce, a także zazębiają się z nimi. Ponad skałami wulkanoklastycznymi występują łupki ilasto-krzemionkowe, czarne łupki i czerty syluru i dewonu (Fig. 2). Skałom osadowym towarzyszą wulkanity należące do bimodalnej, alkalicznej suity: diabazy, tworzące sille w górnej części zespołu mułowców oraz trachity (keratofiry), występujące jako płytkie intruzje lub potoki lawowe wśród skał wulkanoklastycznych. W oparciu o zróżnicowanie składu oraz kryteria strukturalno-teksturalne wśród skał wulkanoklastycznych wyróżniono trzy główne grupy (Tabela 1), a w ich obrębie odmiany o różnej wielkości ziarna. Zgodnie z teksturalną, niegenetyczną klasyfikacją skał wulkanoklastycznych Fishera odmiany te określić można jako wulkaniczne zlepieńce, piaskowce, mułowce i iłowce. Odmiany drobno- i średniookruchowe zwykle wykazują wyraźną foliację, grubookruchowe są masywniejsze. Wśród polilitologicznych (wieloskładnikowych) skał wulkanoklastycznych (odsłonięcia 1-3 i 5) dominują wulkaniczne piaskowce i mułowce, przeławicone drobno- lub gruboziarnistymi zlepieńcami. W odsłonięciach oraz w próbach zaobserwo-

wano szereg struktur sedymentacyjnych – uławicenie, gradację wielkości ziarna, laminację oraz bioturbacje (Fig. 3, 4 i 5; Pl. I). Odmiany grubiejziarniste zbudowane są z klastów skał wulkanicznych kwaśnych i obojętnych (Pl. II: 1 i 2), w odmianach drobniejziarnistych dominują drobne blaszki jasnego łyszczyku oraz hematyt i skaleń alkaliczny. Pojawią się też egiryn. Monolitologiczne (jednoskładnikowe) skały wulkanoklastyczne (odsłonięcia 7, 8 i 9) reprezentowane są głównie przez wulkaniczne piaskowce, mułowce i iłowce; podrzędnie obserwowano średnioziarniste zlepieńce. Skały te tworzą prawdopodobnie masywne ławice o znacznej miąższości. Zbudowane są z łyszczykowych klastów tkwiących w łyszczykowym tle (Pl. II: 3 i 4). W znacznej ilości występują minerały nieprzezroczyste a niekiedy chloryty, stilpnomelan i niebieski amfibol. W odsłonięciu 7 obserwowano nieliczne, silnie wezykularne, ostrokrawędziste klasty o wielkości do 15 cm (pumeks?). Skały wulkanoklastyczne bogate w kryształy (odsłonięcie 4) składają się z ziarn kwarcu i albitu frakcji piaszczystej tkwiących w masie łyszczyków (jasny łyszczyk, biotyt, chloryt). Występują też szkieletowe kryształy minerałów nieprzezroczystych. Nie zaobserwowano żadnych struktur sedymentacyjnych. Opisywane skały wulkanoklastyczne reprezentują utwory stosunkowo głębokiego zbiornika morskiego, deponowane w sąsiedztwie aktywnych centrów wulkanicznych. Polilitologiczne skały wulkanoklastyczne interpretowane są zasadniczo jako utwory epiklastyczne, deponowane przez turbulentne spływy grawitacyjne: od spływów o wysokiej koncentracji (zlepieńce o rozproszonym szkielecie ziarnowym), po normalne i rozcieńczone prądy zawiesinowe (pozostałe odmiany). Monolitologiczne skały wulkanoklastyczne mogą reprezentować ignimbryty, pierwotnie złożone głównie z fragmentów szkliwa. Skały wulkanoklastyczne bogate w kryształy wykazują teksturalne i mineralogiczne podobieństwo do przeobrażonych osadów potoków piroklastycznych.

EXPLANATION OF PLATES

Plate I

Polylithologic volcaniclastic rocks from localities 1 and 2. Scale bar is 1 cm long. Way up is generally to the top of photographs. See Fig. 3 and 4 for location of the samples.

1 — Sample 1. The base of the 1.5 m thick bed of polylithologic matrix-supported volcanic conglomerate. Note the concentric structure (the effect of chilling ?) within the light-coloured round acid lava clast.

2 — Sample 2. Fragment of 10 cm long, ellipsoidal acid lava clast set in a finer matrix. Concentric structure of this clast is marked by the change of colour, the distribution of quartz-filled vesicles and by a 1 mm wide dark rim (see Pl. II: 1).

3 and 4 — Samples 3 and 4, respectively. Sedimentary structures typical of turbidites in polylithologic volcaniclastic rocks from locality 2 are visible. See Fig. 5a.

Plate II

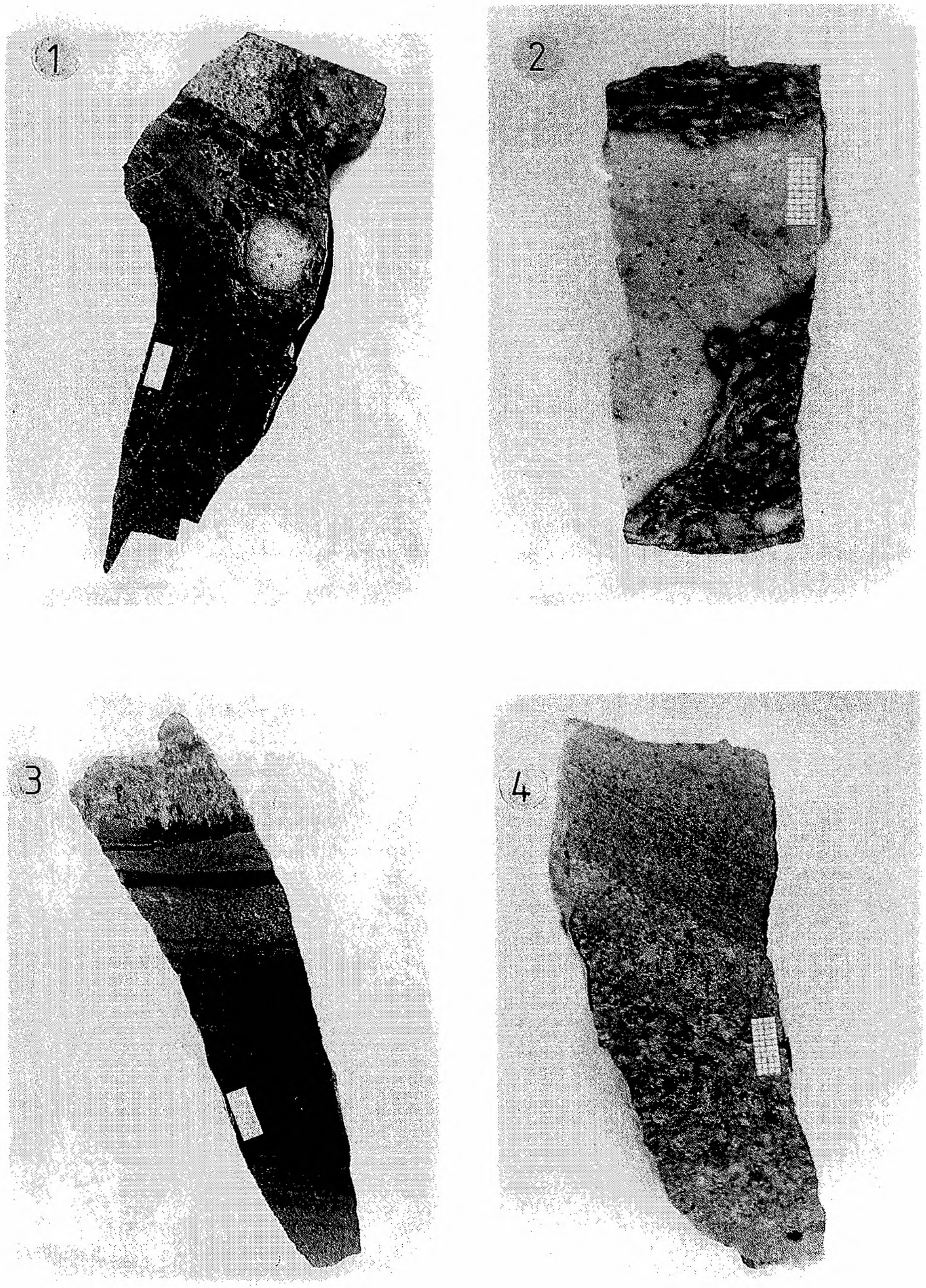
Constituents of the polylithologic volcaniclastic rocks (photos 1 and 2) and the monolithologic volcaniclastic rocks (photos 3 and 4).

1 — Marginal part of the acid lava clast (sample 2, Plate I: 2). Towards the margin of the clast (top of photo) the amount of albite and quartz (white) rapidly decreases and the amount of white mica (grey) increases. Plane polarized light.

2 — Fragment of clast of intermediate volcanic rock with a trachytic texture which is defined by subparallel quartz - white mica - albite pseudomorphs after lath-shaped feldspars. Plane polarized light.

3 — Sample 5. Monolithologic medium-grained volcanic conglomerate. All fragments are strongly flattened parallel to the foliation. The main component of both clasts and matrix is fine white mica (grey). The clasts are rich in opaque minerals (white), while the matrix contains some albite and quartz (black). Negative print. Non-polarized light.

4 — Sample 6. Monolithologic volcanic sandstone. The light clasts are composed mainly of white mica; the matrix is rich in opaque minerals (dark and black). Plane polarized light.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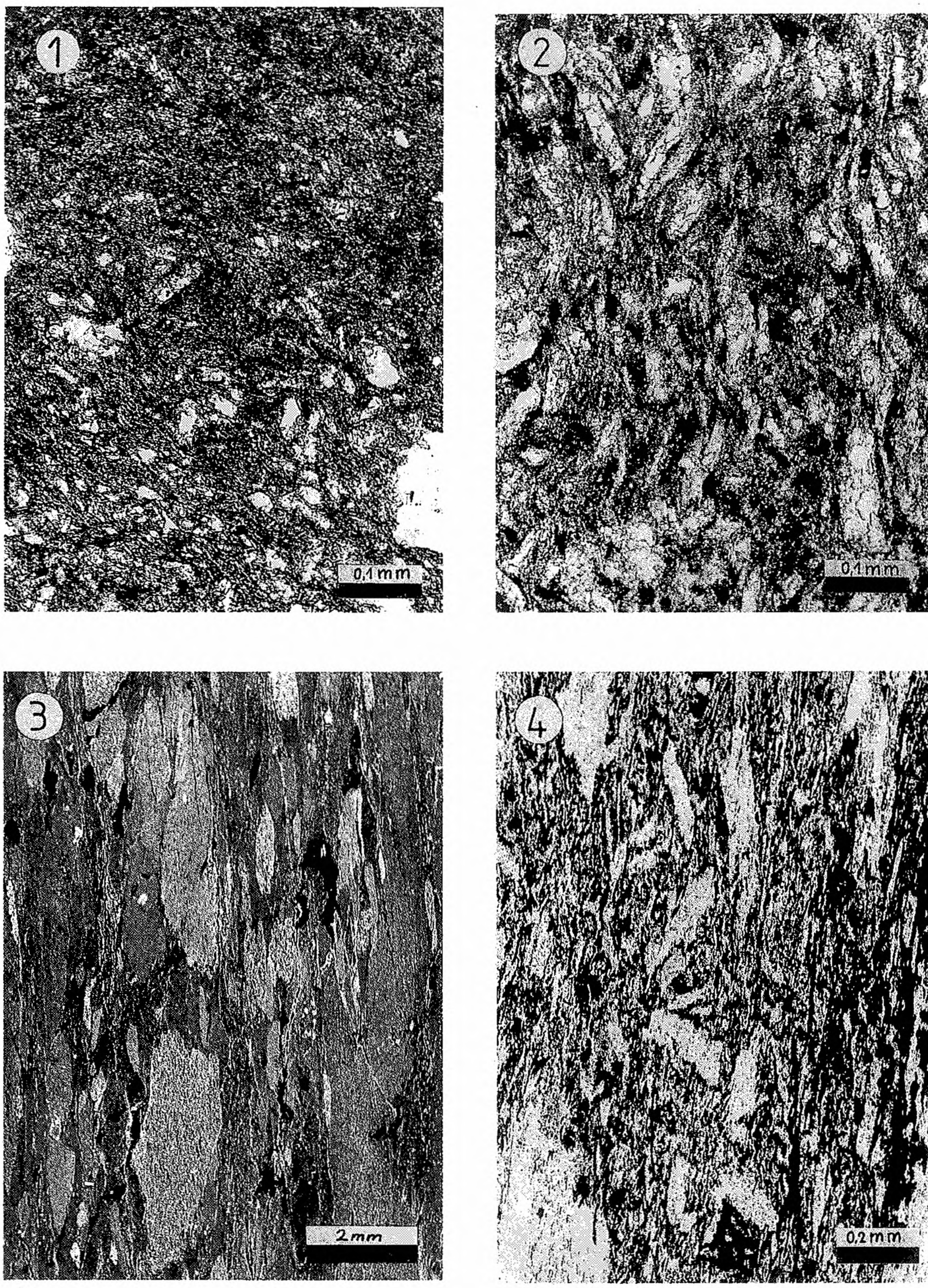
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0,1 mm
3
2 mm
4
0,2 mm