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Sedimentology of deposits from around the Late Caledonian unconformity in the western Holy Cross Mts.

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The Upper Silurian-Lower Devonian section of the western part of the Holy Cross Mts. is composed of greywackes of the Niewachlów Beds, Kielce Beds and Miedziana Góra Conglomerates. They are separated from the terrestrial Gruchawka Conglomerates and Barcza Beds by an erosional surface. Depositional structures recorded in the Silurian greywackes indicate the deep-water sedimentary environment of a flysch facies. The uppermost part of the Kielce Beds and the Miedziana Góra Conglomerates accumulated on a submarine delta fan. These deposits correspond to Late Caledonian molasse and are associated with closure of the Late Silurian basin in the Holy Cross Mts. The Gruchawka Conglomerates, containing fish remains, mark the beginning of the Early Devonian marine transgression. Together with the overlying sandstones and mudstones of the Barcza Beds they form the Old Red Sandstone succession. The Late Caledonian unconformity occurs between the Upper Silurian molasse deposits and Lower Devonian Old Red Sandstone facies, and the stratigraphic gap most likely spans the Pridoli, Lochkovian and lower Pragian. Large thicknesses of Silurian greywackes in the NW part of Kielce, and the high degree of thermal maturity of organic matter, indicate a geotectonic affinity of this region with the Łysogóry Block.

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Key words: Holy Cross Mts., Upper Silurian-Lower Devonian, stratigraphy, sedimentology, Late Caledonian unconformity.

INTRODUCTION

Change in the depositional environment at the Silurian/Devonian transition in the Holy Cross Mts. is expressed by a gradual replacement of deep-water facies by more shallow-water sediments. Those processes, generated mostly by tectonic activity in source areas, proceeded in different ways in the south (Kielce Region) and in the north (Łysogóry Region) of the Holy Cross Mts. (Fig. 1).

No sedimentary continuity is observed in the Kielce Region (Tomczykowa and Tomczyk, 1981), subjected to stronger uplifting movements at the Silurian/Devonian transition. In the Łysogóry Region, there was a continuous shallow-water sedimentation between the Silurian and Devonian (Tomczyk *et al.*, 1977). In the Kielce Region, the Late Caledonian unconformity is marked by a stratigraphic gap between the Upper Ludlow and upper Siegenian (Czarnocki, 1936; Tomczykowa and Tomczyk, 1981; Turnau and Tarnowska, 1997). Different views have been published so far on the origin of this unconformity in the Łysogóry Region. Some authors consider that there was no Late Caledonian orogeny in this area (Mizerski, 1995; Szulczewski, 1995). Other suggest evidence of orogeny in the earliest Devonian-Siegenian (Czarnocki, 1936; Dadlez *et al.*, 1994; Znosko, 1996; Kowalczewski *et al.*, 1998).

A well exposed Silurian/Devonian transition sequence has been described (Malec, 1993) from the construction site of a power station in NW Kielce. These rocks have been interpreted in terms of their succession, stratigraphical position and relation to Palaeozoic orogenic cycles (Fig. 2).

This paper describes the lithologies of the Silurian/Devonian transition sequence exposed in this area and provides evidence of the stratigraphical position of the Upper Silurian greywackes and the source areas of clastic material.

New data on the thermal maturity of organic matter from the Upper Silurian greywackes of NW Kielce is also provided.

THE SILURIAN/DEVONIAN BOUNDARY IN THE NORTHWESTERN PART OF THE KIELCE REGION

The Upper Silurian greywackes are approximately 1200 m thick (Malec, 1993). The lower part of the succession, about

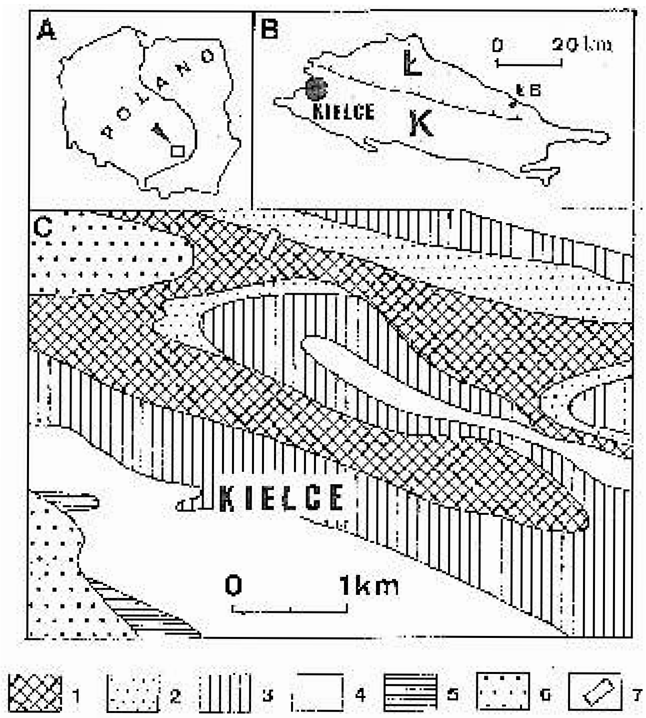


Fig. 1. Location of the study area: within Poland (A), in the regional Palaeozoic fromework (B), and in the NW part of Kielce (C)

1 — Silurian; 2 — Lower Devonian; 3 — Middle Devonian; 4 — Upper Devonian; 5 — Carboniferous; 6 — Permian; 7 — study area (Gruchawka quarter, power generating plant); K — Kielce Region; Ł — Łysogóry Region; ŁB — Łężyce-Bełcz section

800 m thick, is represented by the Niewachlów Beds, composed largely of medium-grained, locally fine- and coarse-grained greywackes with mudstone interbeds. The overlying Kielce Beds are represented by claystones, mudstones and fine-grained greywacke sandstones, approximately 400 m thick. Similar lithologies are observed in a few metres of cherry-red deposits from the upper part of this unit, which are overlain by the coarse-grained Miedziana Góra Conglomerates with an erosional top surface (Figs. 2–4). These, in turn, are overlain by a thin layer of the Gruchawka Conglomerates, and sandstones with mudstones of the Lower Devonian Barcza Beds (Figs. 4–6).

This Upper Silurian profile shows many similarities with coeval deposits in the Łysogóry Region (Fig. 3) where the coarser-grained lower part of the greywacke succession is represented by the Wydryszów Beds. Their upper part belongs to the Rzepin Beds and is composed of claystones, mudstones and fine-grained greywackes containing cherry-red beds with intercalations of carbonates rich in benthic fossils (Czarnocki, 1950; Tomczykowa and Tomczyk, 2000; Malec, 2000*c*, *d*; Kozłowski, 2000). The total thickness of the greywackes in the Łysogóry Region is estimated at 1500–2000 m (Tomczyk, 1962*a*, *b*, 1968, 1974; Filonowicz, 1963, 1968; Tomczykowa and Tomczyk, 1981).

The Niewachlów Greywackes, containing a diverse benthic fauna, were considered to have been deposited in a shallow-water environment. The low degree of rounding and the presence of large claystone and mudstone intraclasts were thought to reflect nearness to source areas and short transport, also by rivers. Sedimentary structures found in greywacke bed were suggested to indicate current and wave activity on a shelf or delta setting (Samsonowicz, 1934; Tomczykowa, 1959; Tomczyk, 1962*b*; Kotański, 1968; Łabędzki, 1969; Przybyłowicz and Stupnicka, 1989, 1991; Romanek and Rup, 1989). A minority view, noting the presence of grain-size grading, considered that the Niewachlów Beds were deposited from turbidity currents in a deep-water environment (Łydka *et al*., 1963). The upper part of the greywacke sequence has recently been separated as a new lithostratigraphic unit — the Kielce Beds (Malec, 1993). These deposits were earlier considered to represent the typical Niewachlów Greywackes (Czarnocki, 1936, 1957; Taszek, 1962; Kowalczewski, 1968).

The uppermost, several metres thick section of the greywacke succession represented by cherry-red deposits, have been assigned to the Downtonian (Czarnocki, 1936), or alternatively considered to belong to the Gedinnian Klonów Beds (Filonowicz, 1971, 1973; Malec, 1993; Szulczewski, 1994, 1995). The Klonów Beds were established a separate unit because the underlying greywackes of the Kielce Beds were included into the uppermost Silurian (Pridoli: *transgrediens* Zone) (Malec, 1993). The latest biostratigraphical data (Tomczykowa, 1993) suggest a late Ludlow age for the Kielce Greywackes and probably for the Miedziana Góra Conglomerates, and so indicate that the Klonów Beds do not lie within the Silurian/Devonian transition sequence in NW Kielce (Fig. 3).

The upper Ludlow cherry-red claystones and greywackes of the uppermost part of Kielce Beds have lithological and age equivalents (older than the Klonów Beds) in the Łysogóry Region. These are cherry-red clay shales with thin interbeds of greywacke sandstones from the Rzepin Beds of the central and eastern parts of the area (Samsonowicz, 1934; Czarnocki, 1950; Tomczykowa and Tomczyk, 1981, 2000). Their stratigraphic position has been documented best in the Łężyce-Bełcz section (Fig. 1) where abundant trilobite, brachiopod and coral faunas occur, indicating a late Ludlow age (Różkowska, 1962; Tomczykowa, 1962, 1991; Biernat, 1981). Typical Klonów Beds lithologies are known from the Łysogóry Region of the Holy Cross Mts. (Fig. 3). Palynological studies indicate a Late Silurian (Pridoli) and perhaps Early Devonian (earliest Gedinnian) age for these deposits (Kowalczewski and Turnau, 1997; Kowalczewski *et al.*, 1998). Most research workers considered the Klonów Beds, because of their redness and lack of any fossils, to represent the terrestrial sedimentary environment of the Old Red Sandstone (Czarnocki, 1936, 1957; Pajchlowa, 1959, 1962, 1968; Łabanowski, 1971, 1990; Tomczykowa and Tomczyk, 1981; Stupnicka, 1989; Szulczewski, 1994, 1995; Stupnicka and Przybyłowicz, 1998). In their type area, alluvial fan, braid plain and braid deltas palaeoenvironments that prograded into a shallow-marine basin have been recognised (Kowalczewski *et al.*, 1998).

The depositional environment of the Miedziana Góra Conglomerates has been disputed. They have been considered to represent either Late Silurian regressive deposits (Tomczyk,

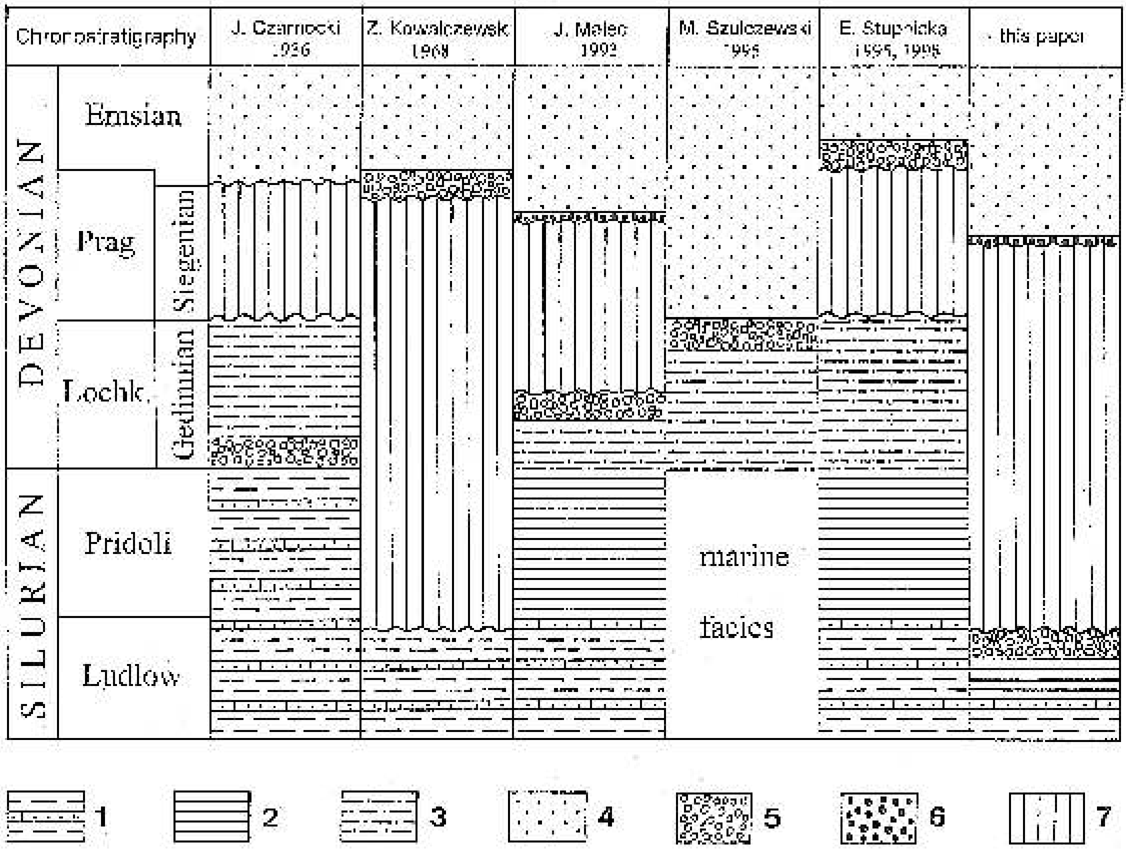


Fig. 2. Position of the Late Caledonian unconformity at the Silurian/Devonian boundary around NW Kielce (thickness not to scale)

1 — Niewachlów Beds; 2 — Kielce Beds; 3 — Klonów Beds; 4 — Barcza Beds; 5 — Miedziana Góra Conglomerates; 6 — Gruchawka Conglomerates; 7 — stratigraphic gap

1968, 1974) or transgressive conglomerates of the Devonian sequence base (Kowalczewski, 1968, 1971). Some authors proposed an alluvial origin for the conglomerates, from south-flowing rivers (Kotański, 1959; Tarnowska, 1988; Szulczewski, 1994, 1995), or suggested deposition from fan deltas prograding from the Kielce and Łysogóry Regions into the shallow-marine (probably lagoonal) Niewachlów-Miedziana Góra basin (Kowalczewski *et al.*, 1998). Continental environments (Łobanowski, 1990) and deposition from debris cones at the foot of slopes and escarpments (Stupnicka, 1995) have also been suggested.

The Miedziana Góra Conglomerates, earlier considered as a lithologically uniform unit, now appears bipartite. Its lower, thicker part comprises the coarse-grained Miedziana Góra Conglomerates, whereas the upper, thinner unit is represented by the fine-grained Gruchawka Conglomerates (Malec, 1993). Both these units are composed of quartzitic sandstone pebbles. The matrix of the Miedziana Góra and the Gruchawka Conglomerates is muddy and sandy, respectively. The matrix of the Gruchawka Conglomerates is sandy, and commonly contains heavy minerals and numerous ostracoderm and placoderm moulds. The transgressive character of the Gruchawka Conglomerates and its fossil content indicate a shallow-marine environment. The Gruchawka Conglomerates are separated from the Miedziana Góra Conglomerates by a distinct sedimentary hiatus (Fig. 6).

Correlatives of the Gruchawka Conglomerates are observed not only in the Kielce section, but also in other areas of the western part of the Łysogóry Region. They form a 0.4–0.8 m-thick unit at the base of the Barcza Beds, unconformably overlying various units of the Lower Palaeozoic (Filonowicz, 1973; Fig. 3). These conglomerates contain quartzitic sandstone pebbles and lithoclasts of red and green clay shales (*op. cit.*).

In NW Kielce, the Gruchawka Conglomerates are conformably overlain by the Barcza Beds (Figs. 4–6), which comprise terrigenous sandstone and mudstone deposits of variable thickness, and which contain quartz grains twice as large as those in the greywacke sandstones of the Kielce Beds (Fig. 4). The mudstones of the lower part of the Barcza Beds contain psilophytes, whereas the sandstones yield fish remains and trace fossils (Czarnocki, 1957; Kotański, 1959, 1968; Malec, 1993). The Barcza Beds probably represent shallow-neritic, lagoonal, and perhaps locally continental sedimentary environments.

In NW Kielce, stratigraphically important Late Silurian fossils have only been found in the greywackes of the Kielce Beds. Well preserved benthic fauna occurs as isolated specimens or, rarely, as shell hashes. These fossils were redeposited from coastal, shallow-water zones, being transported by turbidity currents into deeper waters. They are coeval with the parent rock. No older fossils have been found in lithoclasts within the Kielce Beds.

A trilobite assemblage from the upper part of Kielce Beds contains *Balizoma erraticum* (Schrank), *Dalmanites nexilis*

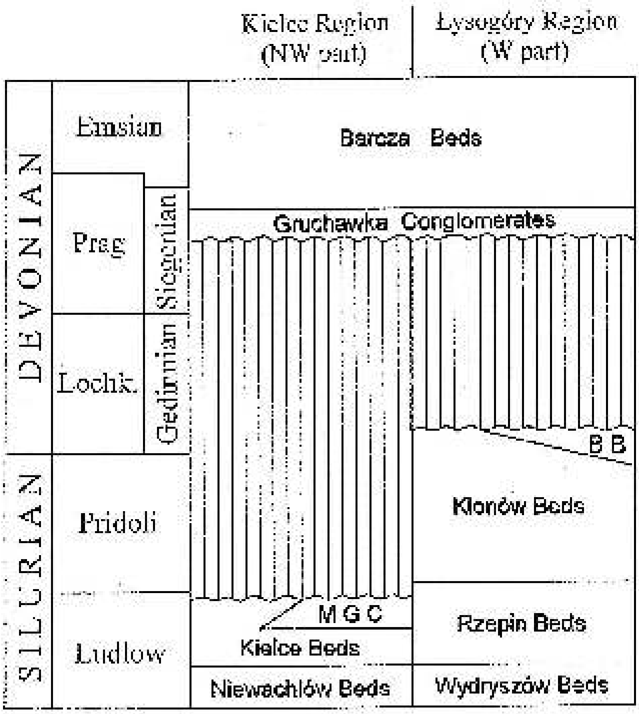


Fig. 3. A stratigraphical scheme of the Upper Silurian and Lower Devonian in the western part of the Holy Cross Mts. (thickness not to scale)

MGC — Miedziana Góra Conglomerates; BB — Bostów Beds

(Salter), *Helokybe* cf. *spio* Thomas and *Richterarges kielcensis* Tomczykowa, indicating a Late Silurian age (Tomczykowa, 1993). The trilobites are accompanied by abundant ostracods referable to *Neobeyrichia lauensis* (Kiesow). This taxon is restricted to the upper Ludlow in Upper Silurian sections of Europe (Wales, Podolia, Baltic Sea area), defining the *N. lauensis* ostracod Zone correlated with the *praecornutus-kozlowskii* graptolite Zones (Gajlite, 1967; Koren *et al.*, 1989; Hansch, 1995). In North Wales this is a characteristic ostracod species of the Upper Leintwardinian Formation from the middle part of the Ludfordian stage (Siveter, 1978, 1989).

Higher in the section, a younger ostracod assemblage contains large leperditiids assigned to *Herrmannina isakovtsyensis* Abushik. This species commonly occurs in the upper Ludlow (upper Ludfordian) Isakov Beds of Podolia, representing the lower part of the *Formosograptus formosus s. l.* graptolite Zone (Abushik, 1971; Koren *et al.*, 1989). No other younger ostracod assemblages, typical of the 6 ostracod zones (*N. regnans*–*N. gedanensis*) from the uppermost Ludlow and Pridoli of the Baltic Sea area (Żbikowska, 1973; Tomczykowa, and Witwicka, 1974; Nehring-Lefeld, 1988; Siveter, 1989; Hansch, 1993, 1995), have been found in the upper, 70 m-thick sequence of the Kielce Beds.

Above, approximately 60 m beneath the base of Miedziana Góra Conglomerates, graptolites (Fig. 4) have been found; originally identified as *Monograptus transgrediens* Perner (Malec, 1993), newly collected, well preserved material has been referred to *Pristiograptus dubius fragmentalis* (Bouček) by L. Teller. In the Silurian of Poland *P. dubius fragmentalis* was found in the Mielnik IG 1 borehole drilled in the Podlasie Depression, in the upper Ludfordian, *latilobatus/balticus* Zone (Urbanek, 1997; Urbanek and Teller, 1997). This taxon occupies a similar stratigraphic position elsewhere in the world, only in Serbia and Altai crossing the Ludlow/Pridoli boundary (Urbanek, 1997; Teller, pers. comm.). Trilobites, ostracods and graptolites place the upper part of the greywackes of Kielce Beds in the upper Ludlow (upper Ludfordian).

The Miedziana Góra Conglomerates, though unfossiliferous, have also been included within the uppermost Ludlow. These deposits are coeval with the top part of the greywackes of the Kielce Beds, as shown by lateral lithofacies transitions, observed around the Silurian/Devonian boundary in NW Kielce (Fig. 6). The absence of the uppermost Silurian (Pridoli) deposits is suggested by the high sedimentation rate of the greywackes. For example, ostracods of the *Neobeyrichia lauensis* Zone occur in a 150–200 m section of the upper part of the Kielce Beds. Assuming a continuously high sedimentation rate for the uppermost Ludlow and Pridoli greywackes (absent in the section), the 6 youngest ostracod zones would be approximately 1000 m thick.

The Lower Devonian sequence includes the Gruchawka Conglomerates and Barcza Beds, probably of late Siegennian (Pragian) and early Emsian age (Figs. 4–6). These deposits are dated by fish remains and psilophytes found in the Barcza Beds (Malec, 1993), which are also called the Placoderm Sandstones because they contain fragments of the Early Devonian fish *Coccosteus* (Czarnocki, 1957; Kotański, 1959, 1968).

Palaeotemperature data suggest a high thermal maturity of organic matter in the Łysogóry Region and a low thermal maturity in the Kielce Region (Bełka, 1990; Szczepanik, 1997; Marynowski, 1999). Palaeothermal investigations of organic matter from the Niewachlów and Kielce Greywackes of NW Kielce also show a high thermal maturity (Malec, 2000*b*). Previous tectonic subdivision of the Holy Cross Mts. have indicated that this area is located in the Kielce Region. However, the thermal history of the NW part of the Kielce Region is more similar to that of the Łysogóry Region.

LITHOLOGY

KIELCE BEDS

The Kielce Beds is approximately 400 m-thick in this area. This paper discusses their upper 140 m. It is composed largely of mudstones and claystones with subordinate greywacke sandstones (Fig. 4). Most sandstone bases are planar and sharp. Greywacke bed tops show fining upwards from fine-grained sand through silt into clay. Unweathered deposits are black, whereas the weathered rock shows olive and grey-greenish colours. Some sandstone beds are beige-brownish. Only at the top are greywackes cherry-red in colour.

The greywacke sandstones correspond largely to sublithic wackes and quartz wackes (Pl. IV, Fig. 1). Grains comprise mostly fine, variably rounded quartz, averaging 0.08–0.10 mm, maximum 0.40 mm, in diameter (Fig. 4), with subordinate feldspars and micas. Only upper graded units contain quartz grains up to 1.5 mm in diameter (Fig. 4). Extremely large quartz grains (up to 2.2 mm) have been noted only in a tuff layer (Fig. 4, sam-

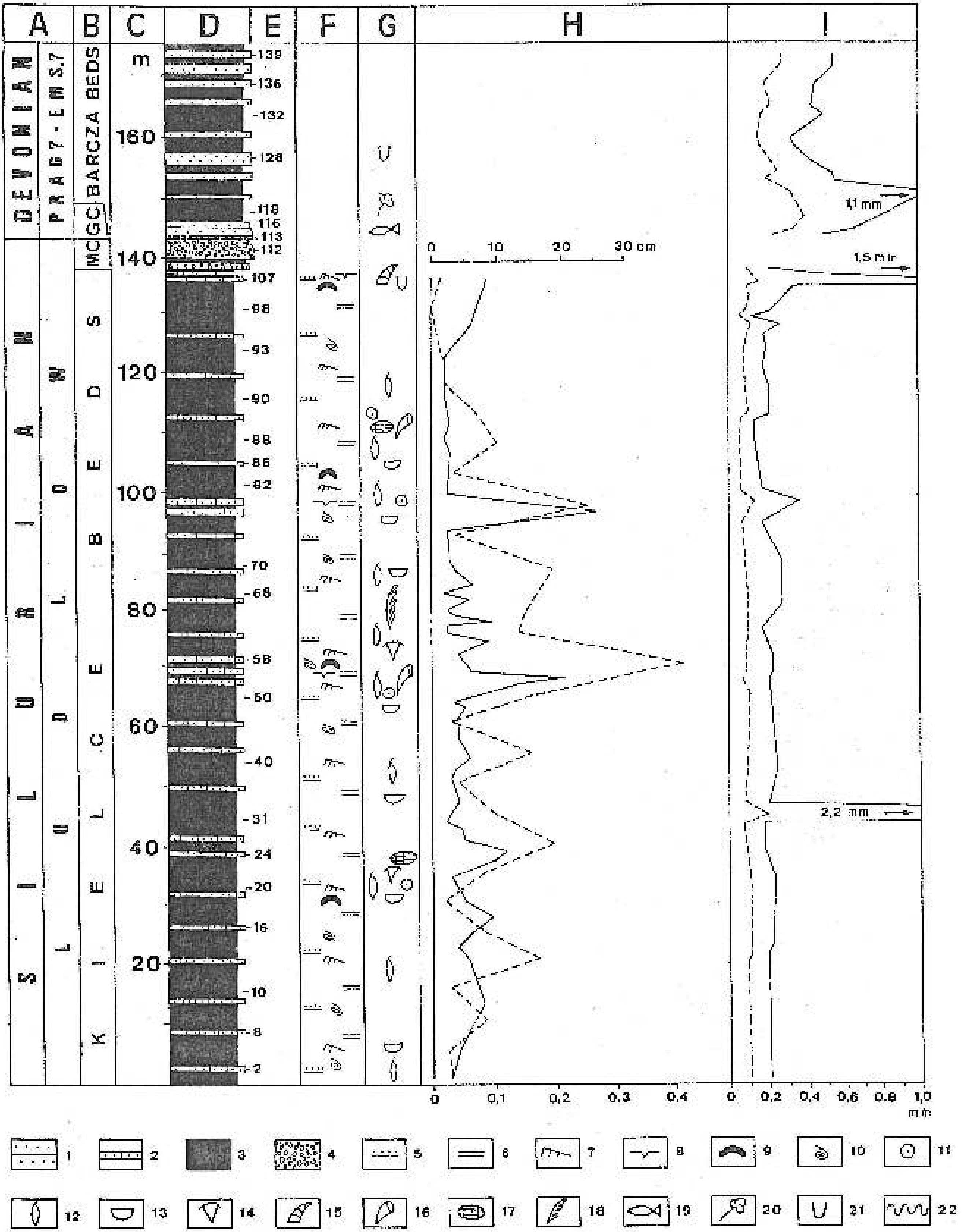
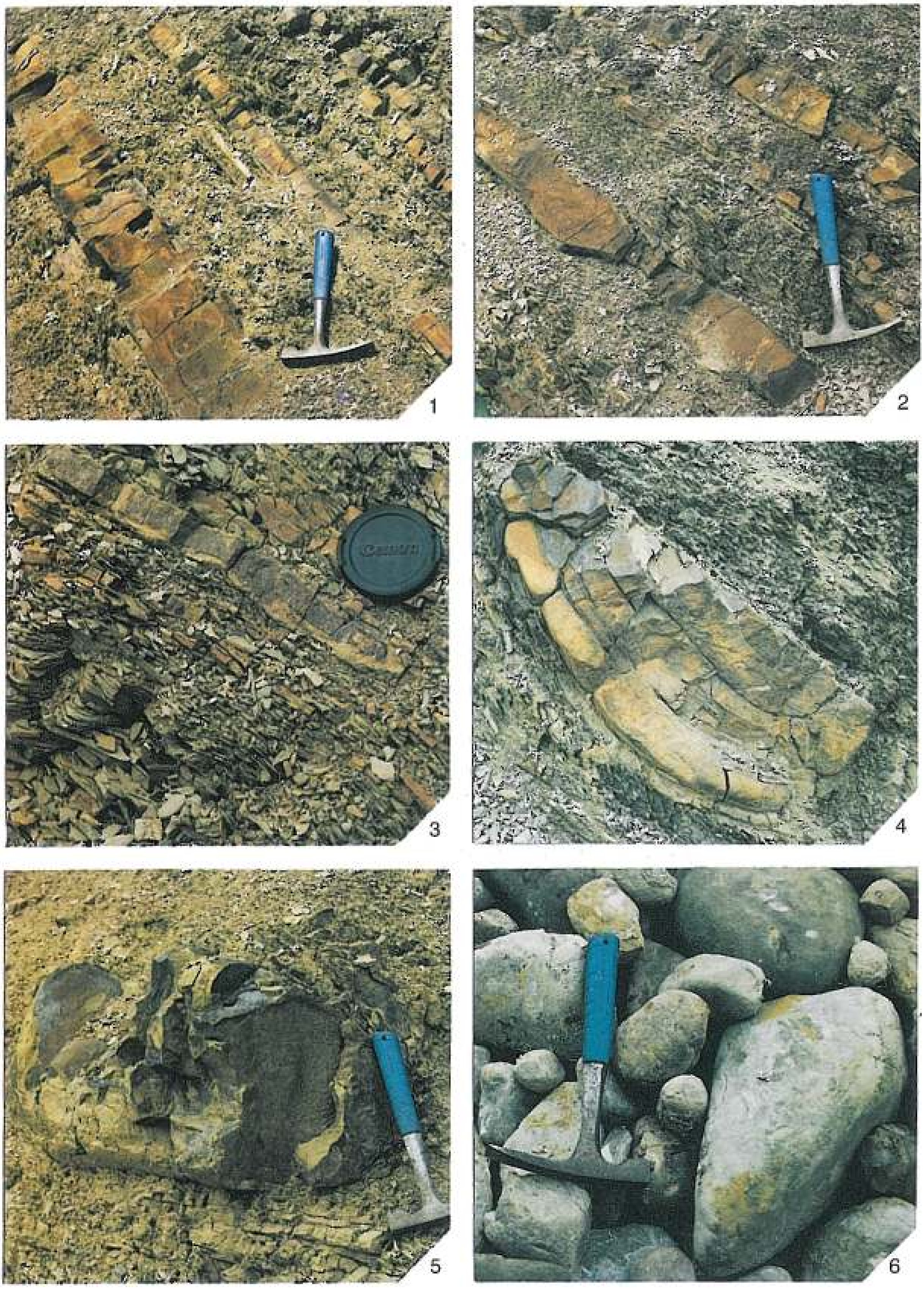


Fig. 4. Lithological log of Upper Silurian and Lower Devonian deposits from NW Kielce

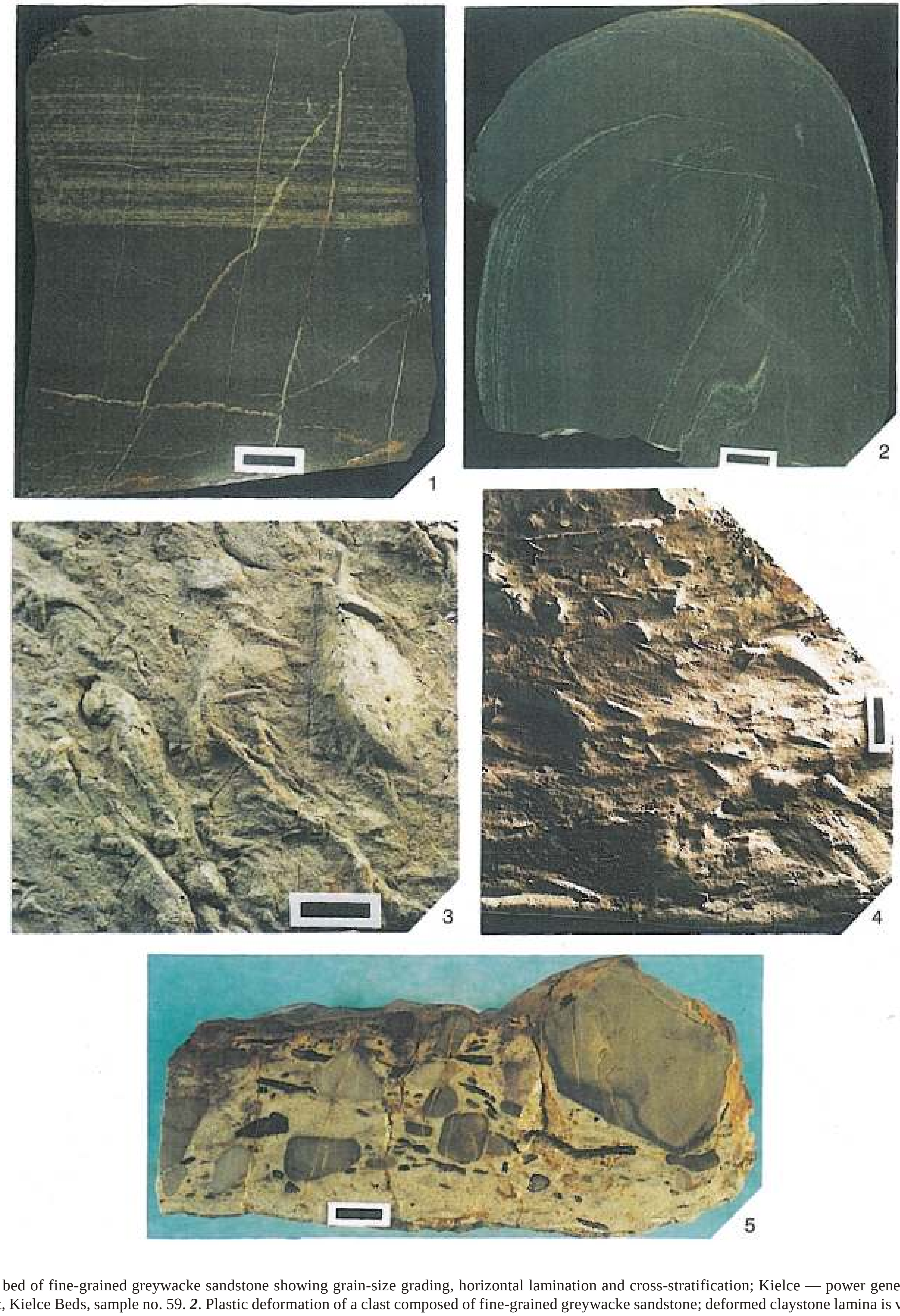
A — chronostratigraphy; B — lithostratigraphic units: M. C. — Miedziana Góra Conglomerates; G. C. — Gruchawka Conglomerates; C — thickness; D — lithology; E — sample number; F — sedimentary structures; G — fossil content; H — thickness of sandstone beds and sand/shale ratio: solid line — average thickness of 5 consecutive sandstone beds, dashed line — sandstone/shale thickness ratio calculated for 5 m-intervals; I — size of quartz grains: dashed line — mean value, solid line — maximum value; 1 — quartz sandstones; 2 — greywacke sandstones; 3 — shales (claystones and mudstones); 4 — conglomerates; 5 — grain-size grading; 6 — horizontal stratification; 7 — cross-stratification; 8 — current marks; 9 — claystone intraclasts; 10 — slump structures; 11 — crinoids; 12 — brachiopods; 13 — ostracods; 14 — trilobites; 15 — gastropods; 16 — solitary tetracorals; 17 — massive tabulates; 18 — graptolites; 19 — fish remains; 20 — fragments of psilophytes; 21 — trace fossils; 22 — erosional unconformity

PLATE I



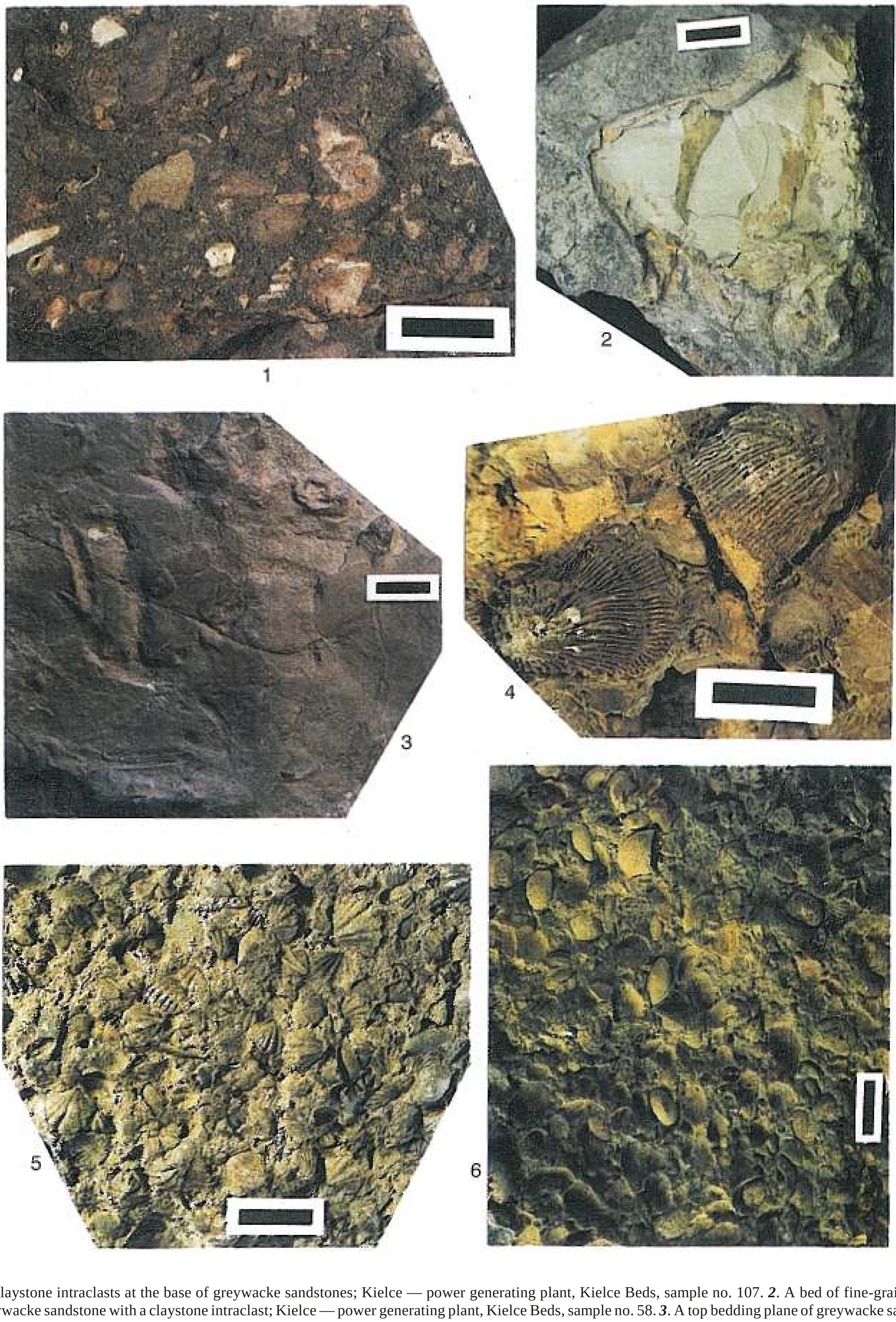
1. Medium and thinly bedded flysch deposits from the upper part of Kielce Beds; Kielce — power generating plant. ***2***. Deformation of a weakly consolidated greywacke sandstone bed; a stage prior to the formation of slump clasts; upper part of the Kielce Beds; Kielce — power generating plant. ***3***. A thin bed of greywacke sandstone within the shale succession from the top of the Kielce Beds; Kielce — power generating plant. ***4***. A deformed clast with a tucked edge, within shales of the upper part of the Kielce Greywackes; approximately 40 cm in length. ***5***. A deformed clast within shales of the top of the Kielce Beds; Kielce — power generating plant. ***6***. Isolated quartzitic sandstone pebbles from the Miedziana Góra Conglomerates; Kielce — power generating plant. Photographs by Jan Malec

PLATE II



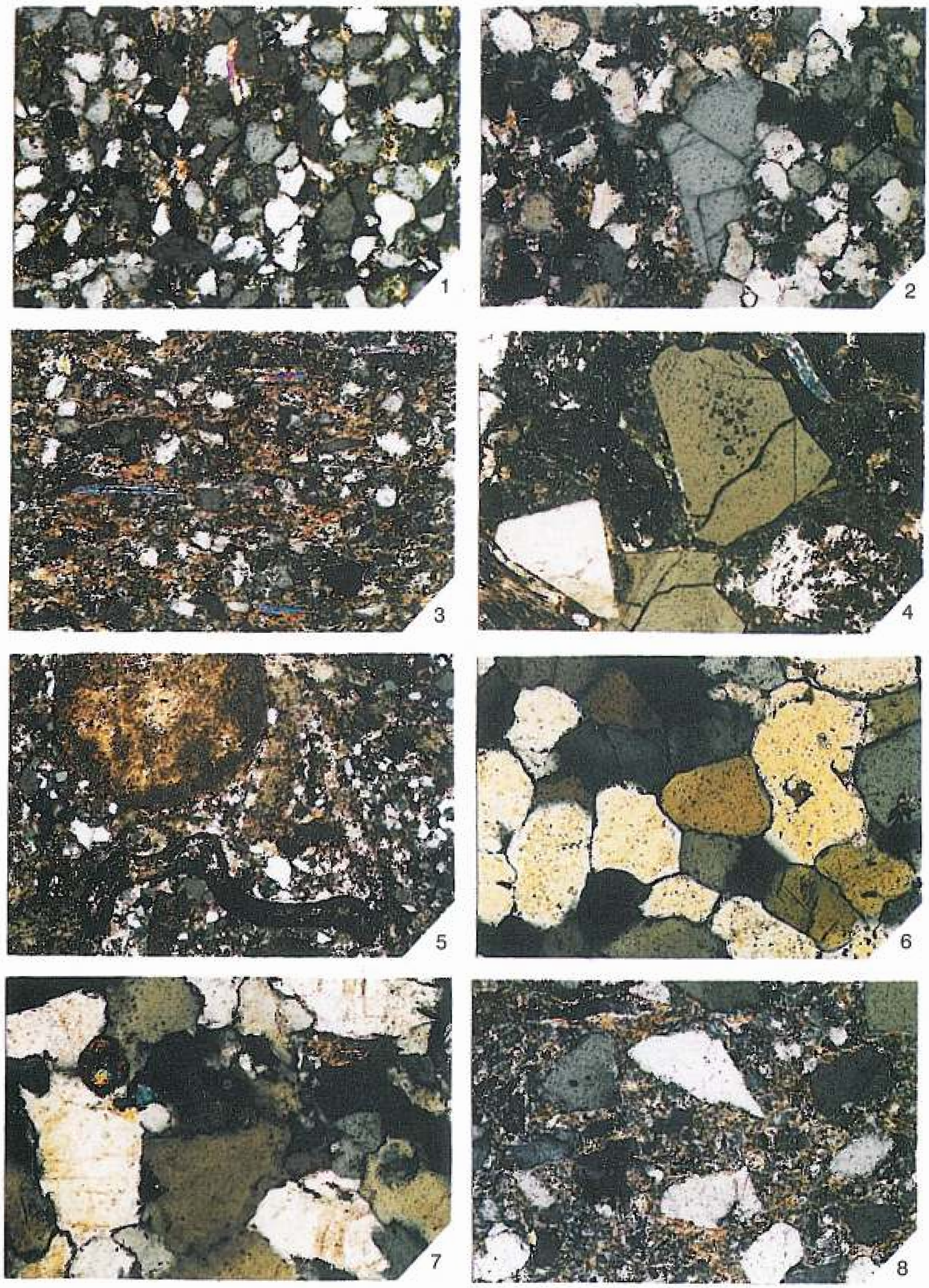
1. A bed of fine-grained greywacke sandstone showing grain-size grading, horizontal lamination and cross-stratification; Kielce — power generating plant, Kielce Beds, sample no. 59. ***2***. Plastic deformation of a clast composed of fine-grained greywacke sandstone; deformed claystone lamina is visible within the sandstone; Kielce — power generating plant, Kielce Beds, sample no. 11. ***3***. Basal plane of a greywacke sandstone bed with biogenic structures and current marks; Kielce — power generating plant, Kielce Beds, sample no. 110. ***4***. Basal plane of a greywacke sandstone bed with current marks; Kielce — power generating plant, Kielce Beds, sample no. 107. ***5***. The Gruchawka Conglomerate (vertical section); moulds of ostracoderms and placoderms are visible; Kielce — power generating plant, sample no. 113; scale bar 1 cm. Photographs by Wojciech Paciura

PLATE III



1. Claystone intraclasts at the base of greywacke sandstones; Kielce — power generating plant, Kielce Beds, sample no. 107. ***2***. A bed of fine-grained greywacke sandstone with a claystone intraclast; Kielce — power generating plant, Kielce Beds, sample no. 58. ***3***. A top bedding plane of greywacke sandstone with trace fossils; Kielce — power generating plant, Kielce Beds, sample no. 107. ***4***. Tetracorals from the basal part of a greywacke sandstone bed; Kielce — power generating plant, Kielce Beds, sample no. 57. ***5***. Brachiopods and ostracods from the basal part of a greywacke sandstone bed; Kielce — power generating plant, Kielce Beds, sample no. 69. ***6***. Ostracods (*Hermannina isakovtsyensis* Abushik), brachiopods and crinoids from the basal part of a greywacke sandstone bed; Kielce — power generating plant, Kielce Beds, sample no. 58; scale bar 1 cm. Photographs by Wojciech Paciura

PLATE IV



1. Quartz wacke with rare micas and feldspars; Kielce — power generating plant, Kielce Beds, sample no. 66, x 87. ***2.*** Quartz wacke with rare micas and feldspars; Kielce — power generating plant, Kielce Beds, sample no. 108, x 87. ***3***. Quartz wacke; horizontal lamination accentuated by horizontal distribution of mica flakes; Kielce — power generating plant, Kielce Beds, sample no. 110, x 87. ***4***. Tuff containing quartz, feldspar, mica and heavy mineral grains; Kielce — power generating plant, Kielce Beds, sample no. 31, x 35. ***5***. Sandy limestone; a cross-section across a crinoid trochite and ostracod test is seen; Kielce — power generating plant, Kielce Beds, sample no. 82, x 35. ***6***. Fine- and medium-grained quartz arenite; a pebble from the Miedziana Góra Conglomerates; Kielce — power generating plant, sample no. 112, x 87. ***7***. Poorly sorted fine- and medium-grained quartz sandstone (quartz arenite) with abundant heavy minerals; cement of the Gruchawka Conglomerates; Kielce — power generating plant, sample no. 113, x 87. ***8***. Sandy mudstone; Kielce — power generating plant, Barcza Beds, sample no. 132, x 87. Photographs by Jan Malec

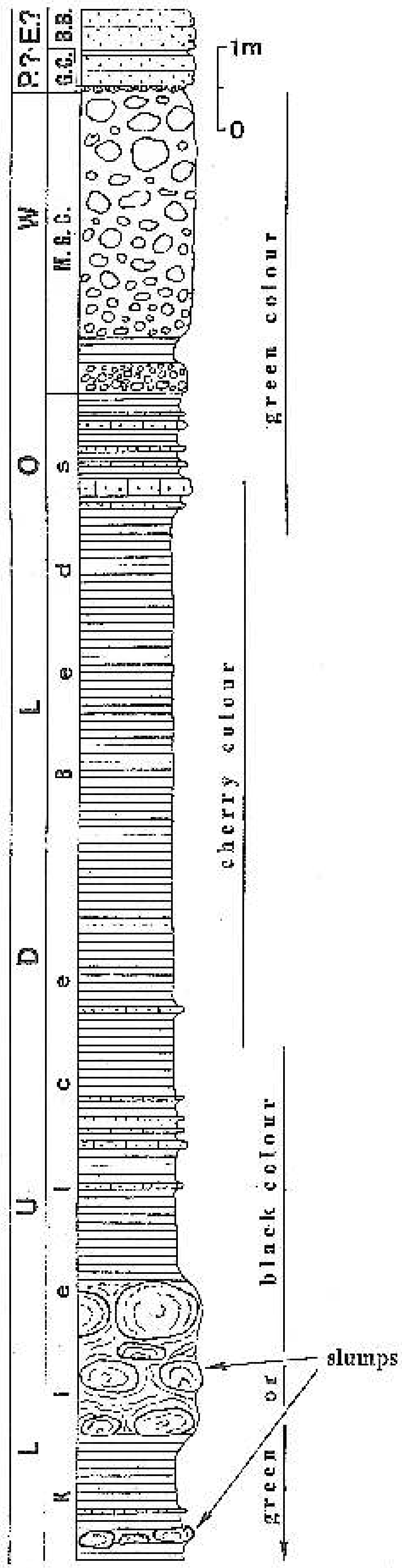


Fig. 5. Part of the Upper Silurian section around NW Kielce

P — Pragian; E — Emsian; M.G.C. — Miedziana Góra Conglomerates; G.C. — Gruchawka Conglomerates; B.B. — Barcza Beds; lithology as in Figure 6

ple no. 31). The greywackes are cemented by clayey-siliceous-ferruginous matter.

The lower part of the greywacke succession (140 m-thick) contains a 10 cm-thick layer of coarse-grained crystal tuff (Fig. 4, sample no. 31; Pl. IV, Fig. 4). In the upper part of the section there is a layer of sandy limestone with bioclasts (15 cm-thick) and abundant fragments of crinoids, tetracorals, brachiopods and ostracods (Pl. IV, Fig. 5).

The greywacke sandstones and mudstones contain relatively abundant, scattered fragments of trilobites, ostracods, crinoids, brachiopods, bivalves, small tabulate corals and solitary tetracorals (Fig. 4; Pl. III, Figs. 4–6). Plankton is represented in claystones by scarce graptolites. The benthic fossils, except for corals, are incomplete. Trilobites occur mainly as isolated segments or pygidia. Combined cephalon and thorax segments are rare. Ostracods, brachiopods and bivalves occur only as individual shells, and crinoids as separated segments. All these fossils are concentrated at turbidite bases, forming redeposited associations with one fossil type dominant and subordinate contributions of other faunal groups from different ecologic niches.

Some of the thicker sandstones beds contain large flattened intraclasts of dark grey claystone, up to 20 cm in diameter and 2–3 cm thick (Pl. III, Fig. 2) above the redeposited fossils. Thinner beds contain rare smaller claystone intraclasts.

At the top of the Kielce Beds, black, green grey — weathering claystones and mudstones pass up into a 8 m-thick red-grey greywacke unit. The lower part of this unit comprises cherry-red claystones and mudstones with individual thin beds of greywacke sandstone, and these are overlain by a banded cherry-red, grey-green bed, in turn overlain by grey-green greywackes (Fig. 5). The topmost part of the Kielce Beds (1.4 m) comprises 6 greywacke sandstone beds (4–23 cm thick) representing fine-grained quartz wackes with micas (using to the classification of Pettijohn *et al.* (1972), modified by Jaworowski, 1987) (Figs. 5 and 6). Basal parts of graded beds contain many claystone and mudstone intraclasts, cherry-red and more rarely, grey in colour. These reach 3 cm in diameter and several millimetres in thickness (Pl. III, Fig. 1). Small gastropods moulds, 2–4 mm in diameter occur. Bed soles show biogenic structures (Pl. II, Fig. 3) and current marks (Pl. II, Fig. 4), whereas top planes show current ripples and abundant traces of invertebrate activity (Pl. III, Fig. 3).

MIEDZIANA GÓRA CONGLOMERATES

The greywackes of the Kielce Beds are concordantly overlain by two conglomerate beds totalling approximately 4.5 m in thickness (Figs. 4–6). The lower bed passes laterally into claystones and greywacke mudstones of the Kielce Beds, whereas the upper one is erosionally truncated at the top (Fig. 6). The conglomerate beds are separated by green-grey, horizontally laminated claystones and mudstones, approximately 0.4 m in thickness.

The conglomerates are composed of well and very well rounded quartzitic sandstone pebbles. In the upper bed, pebbles average 10–15 cm in diameter (maximum 40 cm) (Pl. I, Fig. 6). They are weakly cemented with a muddy cement (Fig. 5). Under the microscope, the pebbles are made of fine-grained quartz arenite composed exclusively of sutured angular or subrounded quartz grains, averaging 0.12 mm in diameter (maximum 0.56 mm) (Pl. IV, Fig. 6). The lower conglomerates show grain-support fabric and normal grading with an upwards-increasing cement content. The upper, thicker (up to 3.5 m) conglomerate bed (orthoconglomeratic at the base) coarsens upwards with an upwards-increasing proportion of soft muddy cement, in which large quartzitic sandstone pebbles "float".

GRUCHAWKA CONGLOMERATES

The erosional top surface of the Miedziana Góra Conglomerates is overlain, with a stratigraphic gap and angular discordance 10°, by a 5–6 cm-thick conglomerate bed composed largely of small (averaging 0.5–1.5 cm in diameter, maximum 4.0 cm) quartzitic sandstone pebbles (Figs. 4–6; Pl. II, Fig. 5). The pebbles are well rounded, tightly cemented with a fine- and medium-grained sandy matrix containing abundant heavy minerals (Pl. IV, Fig. 7). The conglomerate bed also contains many moulds of placoderm and ostracoderm fragments (Pl. II, Fig. 5).

The dip of the Late Caledonian unconformity has been measured between the base of the Gruchawka Conglomerates and the base of the Miedziana Góra Conglomerates or the top surface of the greywacke sandstones of the Kielce Beds (Fig. 6).

BARCZA BEDS

The Silurian/Devonian transition section at NW Kielce is represented by over 30 m of terrigenous deposits of the basal Barcza Beds. These comprise sandstones and mudstones with tuffite interbeds (Figs. 4–6). Sandstone beds are represented mostly by arenites and rare quartz wackes, composed of subrounded and angular quartz grains averaging 0.25 mm (maximum 0.5–1.1 mm) in diameter (Fig. 4). The Gruchawka Conglomerates are overlain directly by a 3.3 m-thick succession of light grey, fine-grained quartzitic sandstones (quartz arenites) with mudstone interbeds at the bottom. Above, there lies about 4.0 m of horizontally laminated light grey mudstones containing abundant fragments of psilophytes in the basal 20 cm-thick layer. The upper part of the Barcza Beds is composed of alternating mudstones and sandstones, several tens of centimetres up to a few metres in thickness. In the lower part, these deposits are light and dark grey in colour. Mudstone beds show horizontal lamination. The middle part contains an approximately 8.5 m-thick bed of cherry-brown mudstones (Pl. IV, Fig. 8), most likely with an admixture of pyroclastic material and subordinate sandstone layers. The mudstones are composed of small pseudolumps of different sizes and irregular shapes, cemented with clayey-muddy cement. The topmost parts of the exposed section are represented by grey-green, fine-grained and horizontally laminated sandstones and mudstones.

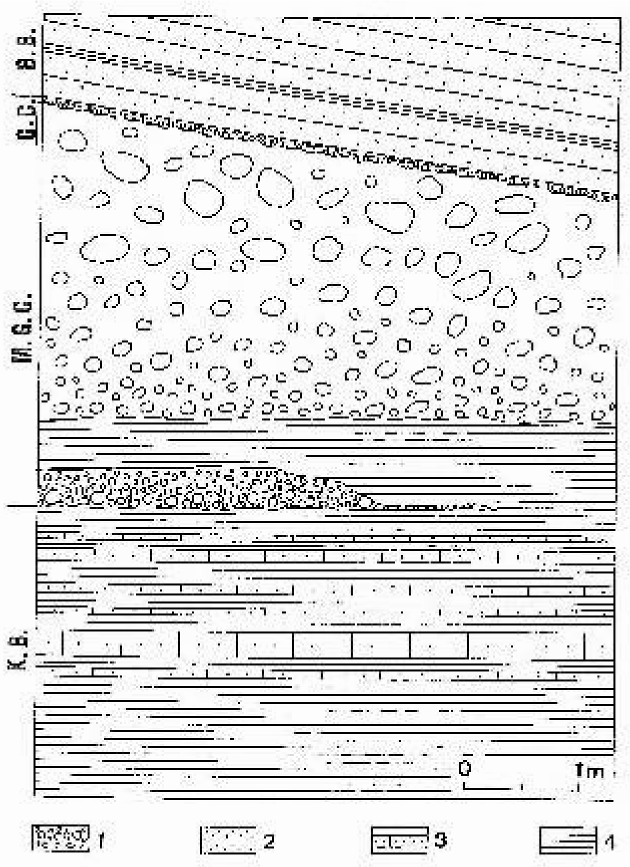


Fig. 6. Part of the Silurian/Devonian boundary section with the Late Caledonian unconformity from NW Kielce

1 — conglomerates; 2 — quartz sandstones; 3 — greywacke sandstones; 4 — claystones and mudstones; K.B. — Kielce Beds; M.G.C. — Miedziana Góra Conglomerates; G.C. — Gruchawka Conglomerates; B.B. — Barcza Beds

SEDIMENTOLOGY

Sedimentological investigations were performed on a well-exposed 140 m-thick section of the upper part of the Kielce Beds. Preliminary results were given by Malec (1996, 1997). Studies focussed on all the sandstones. Patterns of bed thickness were determined and sedimentary structures recorded. Grain-size grading, horizontal lamination, cross stratification, current ripples, current marks and biogenic structures were characterised. Slump structures were also discussed.

SEDIMENTARY STRUCTURES

Bedding. Both thin and thick layers of the exposed Kielce Beds maintain relatively constant thicknesses (Pl. I, Fig. 1). No bed amalgamations, pinchouts or lenticular bedding have been observed. Sandstone beds are separated by claystone-mudstone

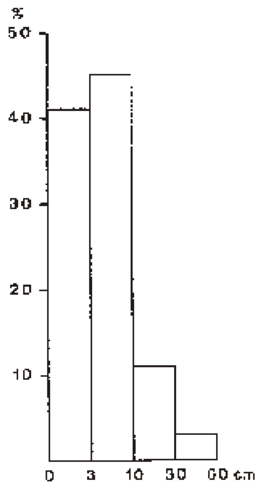


Fig. 7. Thickness distribution of greywacke sandstone layers from the Kielce Beds

units of variable thicknesses, or by homogenous mudstone beds. No beds with slump structures have been considered in the bedding analysis.

Four major thickness clusters of sandstone beds can be distinguished in the Kielce Beds (Fig. 7) on the basis of the Campbell classification (1967). The most common are very thin (up to 3 cm in thickness) and thin beds (3–10 cm) which compose 86.0% of all sandstone beds. The most frequent are beds showing thicknesses up to 4 cm. These constitute approximately 60% of all beds. 11.1% of beds are from 10 to 30 cm in thickness. Thick beds (30–100 cm) are represented by 3 beds ranging from 32 to 37 cm in thickness, 3 beds reaching 40–47 cm, and one 60 cm-thick bed. Individual beds and bedsets show varying thicknesses in different parts of the section. Two sections of the greywacke succession contain bedsets of increased thickness (Figs. 4 and 9A). The upper part of the Kielce Beds (excluding the slump zone, approximately 2 m in thickness — Fig. 5) is dominated by claystones and mudstones with very thin greywacke sandstone interbeds (Figs. 4 and 9B). Only at the very top, beneath the Miedziana Góra Conglomerates, is there a succession of thinly and medium bedded greywacke sandstones (Fig. 6). The 140 m-long section of the upper part of Kielce Beds contains 241 sandstone beds with an average thickness of approximately 5 cm.

Grain-size grading. Grain-size grading is observed on a macro-scale in thicker sandstone layers of the Kielce Beds. In coarser and some of the thinner beds, grain-size grading is accentuated by gradational distribution of organic debris. Most thinner beds show grain-size grading in thin sections only. Quartz grain-size may halve along short, 1.5–2.0 cm, vertical intervals.

Some thinner sandstone beds are probably monofractional. However, the generally fine grain-size makes the percentage of beds showing grain-size grading difficult to estimate.

Plane lamination. Plane parallel lamination occurs in sandstone beds either independently or above the base of grain-size graded and ungraded beds (Pl. II, Fig. 1). It has been observed within 142 beds, i.e. 59% of all sandstone beds. 73 beds (38 very thin, 31 thin and 4 medium beds) show parallel lamination only. Within other beds, horizontal lamination occurs with cross-stratification, in graded or ungraded beds.

Cross-stratification. Small-scale cross-stratification has been observed in 40 beds, i.e. 16.6% of all sandstone beds in this Kielce Beds section. Over 80% of these are very thin and thin beds. Cross-stratification is also present in medium beds, up to 27 cm in thickness. Average thickness of the cross-stratified beds is 1–2 cm, ranging from 0.5 to 3.5 cm. Cross-stratification is observed at the top of beds above horizontally laminated sequences or, sporadically, independently. Two very thin beds (1.0 and 2.5 cm in thickness) show only cross stratification. In the remaining beds it is accompanied by horizontal lamination, grain-size grading or non-grading. Neither convolute structures nor erosional scours have been observed within the cross-stratified beds.

Current ripples. Individual sets of current ripples are observed on the upper surfaces of beds which show well-developed cross stratification. The current ripples are commonly, 0.5–1.5 cm in height with wavelengths up to 10 cm. Sandstone laminae on up current slopes are variously inclined, depending on ripples height. Current ripples are mostly rare and occur as straight and sinuous crests, indicating low flow velocity. Numerous current ripples are observed, however, at the top of Kielce Beds, within the greywacke sandstones immediately underlying the Miedziana Góra Conglomerates. Their crests are short and curved, indicating higher current velocities (*cf.* Gradziński *et al.*, 1986).

Current marks. No sole marks were observed throughout most of the Kielce Beds, where soles are commonly smooth and sharp. Small current structures, resembling prod moulds,

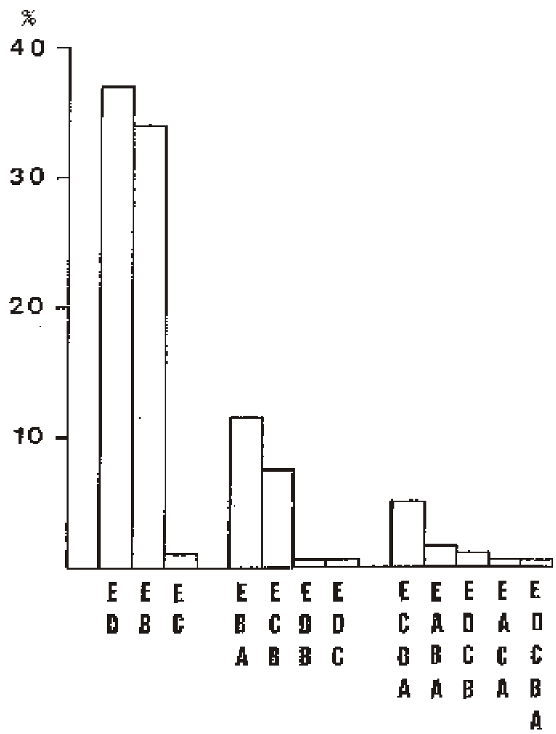


Fig. 8. Sedimentary cycles recorded in the Kielce Beds (A–E — divisions of the Bouma sequence)

have sporadically been noted only at the bottom of thicker beds. Well-developed current marks occur at the top of the Kielce Beds, on lower bedding planes of cherry-red greywacke sandstones. These are represented by relatively large groove marks and small prod moulds (Pl. II, Figs. 3 and 4).

Biogenic sedimentary structures. Biogenic sedimentary structures are rare in the greywackes of the Kielce Beds. Small *Chondrites*? ichnofossils have been observed only on some sandstone tops. More abundant trace fossils occur at the top of the Kielce Beds, in greywacke sandstones underlying the Miedziana Góra Conglomerates where bioturbation is common on both upper and lower bedding planes (Pl. II, Fig. 3; Pl. III, Fig. 3). On bed tops they are represented by small crawling or feeding traces and single dwelling traces, 0.5 cm in diameter and 1.0 cm deep, probably of the ichnofacies *Skcolithos* and *Cruziana*.

Slump structures. Both top and basal surfaces of slump structures of the Kielce Beds greywacke's are in sedimentary contact with undeformed deposits. Coherent slumps (using the classification of Dżułyński, 1963) are dominant, where individual bed fragments remain in contact, are thrust over one another or are separated by muddy matrix. There are also deformed continuous beds, preserved "frozen" at a stage prior to their breakup (Pl. I, Fig. 2). Sporadical slump balls, up to 0.5 m in diameter, are also observed. These show that the sediment was plastic during deformation. Incoherent slumps, represented by individual deformed clasts often with tucked edges, are less common (Pl. I, Figs. 4 and 5; Pl. II, Fig. 2). Slump beds and clasts are of the same fine-grained sandstone as that in adjoining undeformed beds. They contain sedimentary structures indicating deposition from turbidity currents. Load casts were observed at the bases of some slump beds. Slump structures are characteristic of thick sandstone beds only: the lower thickness limit for deformed beds is approximately 10 cm.

Slumping was at a maximum during sedimentation of the upper part of the Kielce Beds. The total thickness of deformed beds in the lower 100 m of the greywackes is approximately 2.0 m, whereas in the upper 40 m it is approximately 3.4 m. A total of 15 smaller or larger slump zones, up to 2.0 m thick, have been observed across the 140 m-thick section (Fig. 5). They represent synsedimentary slumps associated with gravity flows, generated most likely by seismic shocks and vertical tectonic movements at the basin margins.

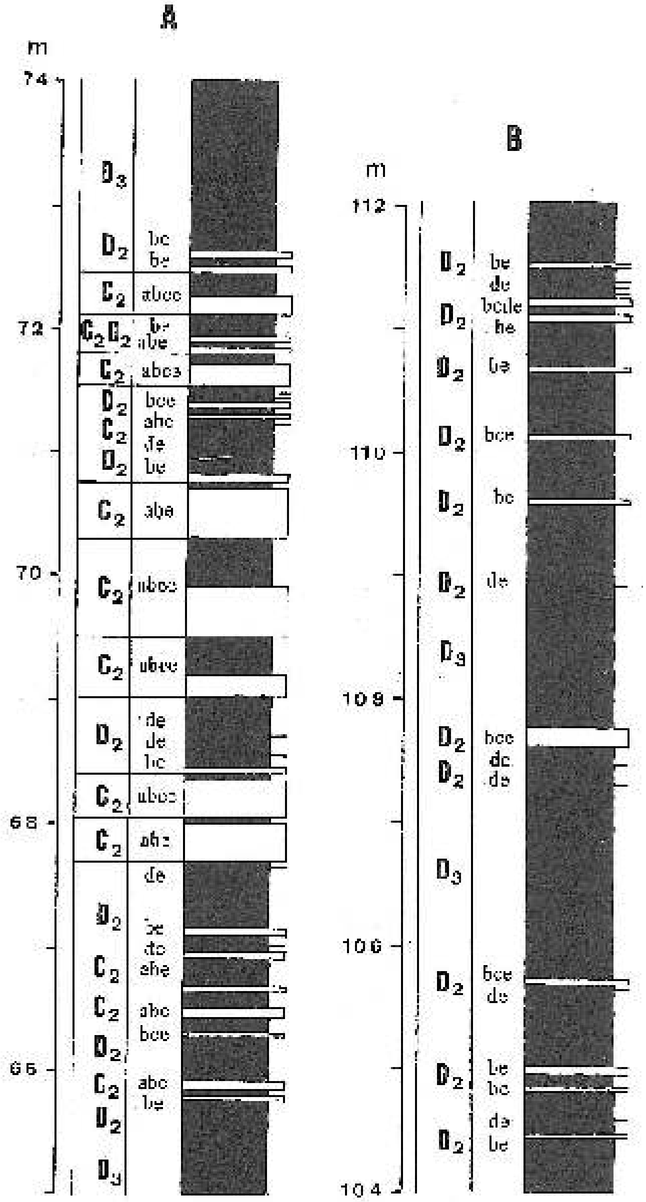


Fig. 9. Selected parts of the Kielce Greywackes (Kielce — power generating plant)

C_2, D_2, D_3 — facies associations after Mutti and Ricci Lucchi (1975); abcde — divisions of the Bouma turbidite sequence; white — greywacke beds; black — shales (claystones and mudstones)

SEDIMENTARY CYCLES

The succession of sedimentary structures in sandstone layers of the Kielce Beds is typical of turbidity currents (Fig. 8), corresponding largely to an incomplete Bouma sequence (1962). Grading represents the Ta division, horizontal lamination corresponds to the Tb division, and cross stratification represents the Tc division. Quantitative data concerning the Td division, given below, are approximate probably because its contribution to the profile is underestimated. The real frequency of the Td division in the studied deposits is probably higher, as it may be "hidden" at the topmost parts of Tb and Tc divisions. Individual sandstone beds, composed of various elements of the Bouma sequence, form (together with the overlying shale-pelagic deposits) characteristic sedimentary cycles.

Double-division cycles are dominant within the sandstone beds (Tbe, Tde, Tce). They compose approximately 72.5% of all sandstone beds. Triple-division cycles (Tabe, Tbce, Tbde, Tcde) make up 19.5% of all cycles, whereas four- and five-division cycles (Tabce, Tabae, Tbcde, Tacae, Tabcde) — 8.0% (Fig. 8).

Thicknesses of sandstone beds in double-division cycles with horizontal lamination (Tbe, Tde) range from 1.0 to 15.0 cm, averaging approximately 4.0 cm in thickness.

The contribution of very thin beds is equal for Tbe and Tde cycles; about 49% for each.

Among triple-division cycles the most common, approximately 94% of all cycles in this group, are Tabe and Tbce sequences. The former is characteristic of thick beds (about 11 cm on average), whereas the latter commonly occurs in beds more than twice as thin, with an average thickness of 5 cm. The thickness of the Tb division with horizontal lamination ranges between 1.5 and 9.0 cm in Tabe cycles, and between 2 and 4 cm in Tbce cycles.

Four-division cycles occur mostly within 3.5–27 cm-thick beds averaging approximately 8.5 cm thick. Tb divisions with horizontal lamination are as thick as in Tabe cycles (4.4 cm).

More compact mudstones and some claystone-mudstone units show well-developed sedimentary structures typical of turbidity currents. Thicker mudstone beds contain (above a basal structureless part frequently with redeposited fauna) parallel lamination followed by a cross-laminated layer.

Claystone-mudstone units are characterised by mudstone layers with sharp basal planes. Lower parts of mudstone units are horizontally laminated, higher in the section they show discontinuous wavy lamination which gradually passes upwards into a thin dark grey and black claystone bed without any sedimentary structures visible. This type of sedimentation corresponds to muddy turbidites described by Stow and Shanmugam (1980). Turbidites of the Kielce Beds are composed mostly of upper divisions (T3–T8) of low-density turbidity currents.

FACIES ASSOCIATIONS

The following features of the Kielce Beds are characteristic of deep-water facies (*cf.* Mutti and Ricci Lucchi, 1975; Stow, 1986; Miall, 1990): predominant mudstones and claystones in the succession, subordinate and mostly thinly bedded fine-grained sandstones, constant lateral thicknesses of sandstone beds, sedimentary structures typical of turbidity currents, and the presence of planktic and redeposited benthic fauna. Several major and a series of minor facies types can be distinguished within deep-water deposits, dependent on mechanisms of deposition and the character of the sedimentary environment (Mutti and Ricci Lucchi, 1972, 1975; Pickering *et al.*, 1986; Ghibaudo, 1992). Individual facies and subfacies have been distinguished on the basis of sedimentological features of particular beds or bedsets, such as: bed thickness, sand/shale ratio, grain-size, type of Bouma sequence, sedimentary structures and bed geometry.

According to the turbidite facies scheme of Mutti and Ricci Lucchi (1972, 1975) greywacke deposits of the Kielce Beds correspond to facies C and D. The former is represented mostly by subfacies C_2, composed of fine-grained sandstones with a basal Ta Bouma division and a complete or incomplete set of its upper divisions. Facies D, lacking in the basal Ta division, occurs most often as subfacies D_2 and D_3. The former is characterised by the presence of beds composed largely of Tb–e, Tc–e and Tde divisions where the sand/shale ratio is below 1, reaching very low values. The latter, devoid of sandstone beds, comprises those parts of the section, composed of claystones and mudstones, that corresponds to the Te division of the Bouma sequence.

The most commonly observed succession within the Kielce Beds is an alternation of facies C and D, with the latter being dominant (Fig. 9B). There are also some sections of facies C dominant (Fig. 9A). The lower part of the cherry-red greywackes from the top of the Kielce Beds is composed of facies D (subfacies D_3), whereas their upper part is represented by facies C (subfacies C_2).

The Miedziana Góra Conglomerates, which conformably overlie the greywackes of the Kielce Beds, correspond in general to coarse-grained deposits of subfacies A2, according to the facies scheme of Mutti and Ricci Lucchi (1972, 1975). This subfacies is characterised by the presence of structureless and reversely graded conglomerates. According to the facies model of Pickering *et al.* (1986) the conglomerates represent subfacies A1.2 (disorganised muddy gravels) within facies A. In the scheme of Ghibaudo (1992) they correspond to subfacies mG (massive gravel) of facies G (gravel beds).

SOURCE AREA

Views on the origin of clastic material from the Upper Silurian greywackes of the Kielce Region have been inferred mostly from studies of the lower, coarse-grained part of the Niewachlów Beds. These deposits contain the coarsest grains and most diverse range of detrital components represented by various sedimentary and igneous rocks (including effusive, plutonic and vein rocks) as well as metamorphic rocks (gneisses) (Ryka, 1959; Łydka *et al.*, 1963; Łabędzki, 1969; Chlebowski, 1978; Romanek and Rup, 1989; Przybyłowicz and Stupnicka, 1989, 1991; Stupnicka *et al.*, 1991; Migaszewski, 1998; Malec, 2000*a*). Due to the varied petrographic composition of the greywackes, several different regions have been considered as potential source areas. Most research workers suggested their location outside the Palaeozoic core of the Holy Cross Mts., e.g. in the Silesia-Kraków area (Znosko, 1974), in the southern, south-eastern and eastern peripheries of the Palaeozoic core of the Holy Cross Mts., in Slovakia below the Carpathians (Kowalczewski, 1974; Chlebowski, 1978; Znosko, 1983; Romanek and Rup, 1989) or to the north or north-east (Stupnicka, 1992; Stupnicka and Przybyłowicz, 1998) and north-west (Znosko, 1983) of the Holy Cross Mts. Local origin of detrital material of the Niewachlów Greywackes has also been proposed. Individual greywacke beds were considered to have been associated with volcanic eruptions around the Bardo and Daleszyce Synclines (Przybyłowicz and Stupnicka, 1989, 1991; Stupnicka *et al.*, 1991; Migaszewski, 1998).

Preliminary studies of the orientation of current marks on basal planes of greywacke sandstones of the Niewachlów Beds from the Kielce Region show that detrital material was transported from the south-west and west?, from outside the Małopolska Block (Malec, 2000*a*; unpublished data). Such source area can be proved by the coarse fraction of the Niewachlów Greywackes of the Kielce Region, compared with those from the coeval Wydryszów Greywackes of the Łysogóry Region (Malec, 2000*a*, *b*, *d*). This location of the source area is also proved by petrographical investigations of the greywackes coeval with the Łapczyca Formation, in the southern and southwestern margins of the Małopolska Block (Łydka *et al*., 1963; Buła, 2000). The Łapczyca Greywackes represent coarser-grained deposits than the Niewachlów Greywackes. It is very likely that some of Old-Palaeozoic terranes (which compose the present-day Sudetes, and may have occupied a position close to the Małopolska Block during the Late Silurian) were the source area for the greywackes. Large amounts of igneous (including effusive) rock fragments in the lower part of Niewachlów and Wydryszów Greywackes indicate that a volcanic arc, situated SW of the Holy Cross Mts., was one of the major source areas.

The fine-grained detrital material of the Kielce Beds greywacke's points to a pronounced change in sedimentation. It was caused most likely by a partial change of the source area. High maturity (dominant quartz grains) and good sorting of the greywacke material from the Kielce Beds may indicate that it originated from resedimented older greywackes corresponding to the Niewachlów Beds. The Małopolska Block, including the southern part of Kielce Region, may have been one of the recharge areas for the greywackes. In the late Ludlow this area was subjected to uplift accompanied by a gradual shallowing of the basin, that also resulted in sedimentation of biogenic carbonates on the shelf with lagoons, as shown by individual beds of sandy limestones with abundant benthic fauna (also present in greywacke sandstones and mudstones) and lagoonal ostracods, found in the upper part of the Kielce Beds. Many more carbonate interbeds with redeposited shallow-water benthic fossils can be observed in the coeval Rzepin Greywackes of the Łysogóry Region (unpublished author's data).

A new transport direction of terrigenous clastics to the basin is shown by the presence of cherry-red claystone lithoclasts found in cherry-red and celadon greywacke sandstones of the uppermost part of greywacke succession. Lithoclasts of this colour are absent from the lower part of the greywacke succession from the Kielce Beds. They were resedimented most likely from the northwestern areas of the Łysogóry Region after the emergence of this area and sedimentation of cherry-red claystones along its margins. The position of the Late Silurian source area in this part of the Holy Cross Mts. can be inferred from local coarser-grained deposits (up to fine pebbles) of the Klonów Beds (Kowalczewski and Turnau, 1997; Kowalczewski *et al.*, 1998).

Different views have been developed by geologists concerning the source area of the Miedziana Góra Conglomerates. Some authors suggest derivation from the Łysogóry Region (Czarnocki, 1936; Kowalczewski, 1968; Malec, 1993), in the Kielce Region (Czarnocki, 1957; Kotański, 1959; Tarnowska, 1988; Szulczewski, 1994, 1995; Stupnicka, 1995) or in both those areas (Kowalczewski *et al.*, 1998). The analysis of grain-size data, lithological and petrographical features of pebbles, and thickness of the Miedziana Góra Conglomerates suggest a Łysogóry provenance. The thickness of Miedziana Góra Conglomerates increases from the south-east towards the northwest. In the eastern part of Kielce (Szydłówek) their thickness is 1.0 m, and in the northwestern part of Kielce — approximately 4.5 m, at Niewachlów — 12.0 m, in the Miedziana Góra area — 40.0 m, whereas in Porzecze (3 km west of Miedziana Góra) — approximately 120–140 m (Czarnocki, 1936; Kowalczewski, 1966, 1968, 1971; Filonowicz, 1973; Studencki, 1978; Malec, 1993). An increase in pebble size also, to occurs approximately 1 m in diameter at Miedziana Góra (Czarnocki, 1936; unpublished author's data), together with a decrease in the degree of roundness in this direction. Lithological and petrographic features show that the sandstone pebbles from the Miedziana Góra Conglomerates correspond to quartzitic sandstones of the Wiśniówka Sandstone Formation, that form the Main Range of the Holy Cross Mts. In terms of grain-size they represent type I Cambrian sandstones recognised at Wiśniówka by Skórska (1959, fig. 3, pl. XL, figs. 1, 2). In a bipartite division of the Wiśniówka section (series A and B), proposed by Czermiński (1959), the grain-size observed in sandstones from the Miedziana Góra Conglomerates is similar to that from the series A of the northern part of the Wiśniówka Duża quarry.

This type of sandstones is unknown from the Cambrian section of the Kielce Region (*cf.* Michniak, 1959, 1969; Orłowski, 1975; Łydka and Orłowski, 1978), including the Dyminy Anticline located approximately 7 km south of the NW Kielce section (*cf.* Bednarczyk *et al.*, 1971; Orłowski and Mizerski, 1996).

SEDIMENTARY ENVIRONMENT

A range of various sedimentological features enables determination of the sedimentary environment of the Upper Silurian greywackes of the Kielce Beds and Miedziana Góra Conglomerates. A benthic fauna of brachiopods, trilobites, crinoids, ostracods and corals indicates a marine environment. These fossils are typical of a shallow-water, littoral (also lagoonal) basin environment. Their occurrence in turbidity current deposits indicates that they were redeposited into deeper water. Autochthonous fossils are represented by acritarch assemblages and rare graptolites, found in claystones.

No sedimentary structures typical of shallow-water sedimentation (above wave-base) have been found within the Kielce Beds (and Niewachlów Beds, Malec, 2000*a*). Rare current ripples occur on upper bedding planes. Slumps, observed within the Kielce Beds, are composed of deformed sandstone layers with sedimentary structures typical of turbidity currents.

Thicker layers of the Kielce Beds, containing incomplete and, rarely, complete Bouma sequences, correspond to relatively high-density turbidity currents. Intervening mudstones are characteristic of low-density turbidity currents. Sedimentary structures typical of low-density turbidity currents are observed in claystones. In the sequence studied these deposits correspond mostly to incomplete, upper divisions of turbidity currents (T3–T8), according to the classification of Stow and Shanmugam (1980).

Sandstones and claystones contain rhythmically alternating laminae and layers composed in general of fine-grained muddy, silty and fine-sandy material. This indicates stable sedimentary conditions in the depositional environment, also confirmed by constant thicknesses of sandstone beds showing neither pinchouts nor amalgamations. The whole Kielce Greywacke sequence possesses homogenous lithologies and almost uniform grain-size represented largely by quartz (Fig. 4). The black colour of unweathered deposits and very rare trace fossils suggest reducing conditions in the depositional environment.

Sandstone beds and thicker mudstone beds composed of material redeposited from shallower basin zones, as well as slump structures, represent catastrophic sedimentation. The intervening claystones reflect pelagic and hemipelagic sedimentation, termed background sedimentation.

The above-mentioned major sedimentological features of the Kielce Greywackes are typical of deep-water deposits. They are best characterised by a sedimentary model of submarine fans stretching along the foot of basin slopes (*cf.* Mutti and Ricci Lucchi, 1975; Walker, 1978; Stow, 1986; Pickering *et al.*, 1986; Miall, 1990; Boggs Jr., 1995). A predominance of very thin and thin sandstone beds in the sequence (approximately 86% of all beds, Fig. 7), a low sand/shale ratio (~ 0.1, Fig. 4), and the range facies and subfacies present indicate that sedimentation took place in a deep basin. Abundant slump structures prove that greywacke sedimentation probably occurred at the foot or on the lower part of a basin slope. The Kielce Greywackes show all the sedimentological features corresponding to flysch facies (*cf.* Dżułyński and Smith, 1964; Dżułyński and Walton, 1965). Lithologies and sedimentology of the entire Upper Silurian sequence of NW Kielce show that these deposits can related to sequences deposited in remnant ocean basins (*cf.* Ingersool *et al.*, 1995). This is also shown by the succession of Silurian deposits in the Holy Cross Mts., comprising an upward-shallowing sequence typical of ocean basin closure. When traced upwards from the base, the sequence is composed of black graptolitic shales, flysch greywacke facies and molasse facies represented by cherry-red sandstones and mudstones, carbonates and conglomerates. In the study area, the beginning of shallowing and closure of the Late Silurian basin is reflected by the sedimentation of the cherry-red greywackes and Miedziana Góra Conglomerates. The greywackes are composed of material originated probably from the eroded Wydryszów Greywackes, exposed to the surface due to uplift in the NW part of the Łysogóry Region. According to Jaworowski (see Kowalczewski *et al.*, 1998), the cherry-red greywackes from the top of Kielce Beds, considered an equivalent of the Klonów Beds, were deposited on an alluvial fan prograding into a shallow sea, probably a lagoon.

I consider that the cherry-red deposits at the top of greywacke succession were deposited in a deeper sedimentary environment, as shown by both its position above deep-water flysch deposits of the Kielce Beds and its sedimentary structures. The latter are very well pronounced within sandstone beds, being typical of deposition from turbidity currents. A deep sedimentary environment is also suggested by the occurrence of slump structures in the upper part of Kielce Beds, 3 m beneath the base of the cherry-red greywackes (Fig. 5). Clasts of greywacke sandstones, of various size and variably deformed, contain sedimentary structures with Bouma sequence divisions (Pl. I, Fig. 5). The presence of slumps immediately beneath the cherry-red greywackes indicates indirectly that the latter were deposited on a submarine slope. Current marks on lower bedding plane of the cherry-red greywacke sandstones, represented by groove and prod moulds (Pl. II, Fig. 4), indicate energetic currents. The greywackes were deposited most likely on a submarine delta fan. Claystones and mudstones from the lowermost part of the succession were deposited within the lower fan, whereas the top sandstones and mudstones may have been accumulated within the middle fan.

The sedimentary environment of the greywacke sequence was probably similar to that observed on modern submarine deltas (*cf.* Prior and Bornhold, 1989). In western Canada, a similar succession has been deposited on the middle and lower parts of a delta, at depths of 280–390 m, and up to 2.3 km seawards from the river mouth, with the palaeoslope inclination of 10–12°.

Pebbles of Cambrian quartzitic sandstones from the Miedziana Góra Conglomerates are sourced from a different area than the greywacke clasts. The homogenous composition of the pebbles suggests that the recharge area was an uplifting narrow zone. Great thicknesses of the conglomerates, reaching 120–140 m in the NW Holy Cross Mts. (Studencki, 1978; Kowalczewski *et al.*, 1998), indicate the occurrence of a fault zone separating the source area from the deposition site. The sedimentary environment of the Miedziana Góra Conglomerates was associated most likely with the upper part of a submarine delta fan, possibly with a channel lobe or adjacent area. This is shown by the large sizes of the pebbles and the presence of reversely graded layers. Detrital components of the conglomerates were probably mixed to form a high-density debris flow, as shown by a high positive correlation (approximately 8) between bed thickness and maximum grain-size, an upward-increasing content of matrix, and the presence of reversely graded grain frameworks.

Similar features have been recorded in ancient conglomerate formations, considered to represent submarine debris flow deposits (*cf.* Walker, 1975, 1977, 1978; Porębski, 1981, 1984). The sedimentary environment of the Miedziana Góra Conglomerates from NW Kielce resembles that of similar deposits from a modern submarine delta described from western Canada (*cf.* Prior and Bornhold, 1989), where conglomerates are being deposited in the upper part of submarine delta and in the transition zone from upper to middle part, at depths of 80–280 m, 500–1300 m seawards from the river mouth, on a palaeoslope inclined at 10–12°, with a maximum of 27°.

CONCLUSIONS

1. The Upper Silurian section of the NW Holy Cross Mts. is composed of the lithologically varied greywackes and the Miedziana Góra Conglomerates. The lower part of the greywacke succession is an equivalent of the Niewachlów Beds, whereas its upper part correlates with the Kielce Beds. The upper part of the Kielce Beds and the Miedziana Góra Conglomerates is biostratigraphically dated as late Ludlow.

The Lower Devonian is represented by the Gruchawka Conglomerate and the Barcza Beds. The contact between Silurian and Devonian deposits in NW Kielce shows a slight angular discordance and a stratigraphical gap spanning most likely the Pridoli, Lochkovian and Lower Pragian. The Late Caledonian unconformity runs between the Miedziana Góra Conglomerates, included within the Caledonian structural complex, and the Gruchawka Conglomerate and Barcza Beds, representing the Variscan structural complex.

2. The Niewachlów Beds were deposited during increased tectonic activity in the discharge area, situated to the south-west of the Holy Cross Mts. beyond the present limits of the Małopolska Block. A high contribution of volcanic lithoclasts in these deposits indicates that a considerable amount of detrital material was supplied from a volcanic arc. The Kielce Beds are characterised by high mineralogical maturity. Detrital grains are well sorted, and the greywacke material originated in part most likely from resedimented older greywackes, deposited in the Małopolska Block, which are equivalent to the Niewachlów Beds.

3. The characteristic assemblage of sedimentary structures, observed in the greywackes, is typical of deep-water flysch facies. In the Upper Silurian section of NW Kielce the typical flysch facies pass into molasse deposits. The flysch facies are represented by the Niewachlów Greywackes and the main body of the Kielce Beds. The molasse facies consists of cherry-red greywackes at the top of the Kielce Beds and the Miedziana Góra Conglomerates.

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