Geological Quarterly, 2001, **45** (4): 435–454

The Silurian of the Nida, Holy Cross Mts. and Radom areas, Poland — a review

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Modliński Z. and Szymański B. (2001) — The Silurian of the Nida, Holy Cross Mts. and Radom areas, Poland — a review. Geol. Quart., **45** (4): 435–454. Warszawa.

The Silurian deposits of the area are known from both natural exposures and boreholes drilled mainly in the period of 1955–1980. In the south (Nida area) and north (Radom region) they are known from boreholes only. The Silurian succession is monotonous. It comprises shaly deposites in the lower part (Llandovery and Wenlock), and shales, siltstones and sandstones (greywackes) in the upper part (Ludlow and Pridoli).

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Key words: Holy Cross Mts., Silurian, lithology, bio- and lithostratigraphy, lithofacies.

INTRODUCTION

The aim of this paper — like that on the Ordovician in this volume — is to review the data concerning the Silurian in the Holy Cross Mts. area. These data are contained in numerous papers published mainly during the last forty years and mainly in Polish. We hope that such a compilation may be useful for geological work which will follow the geophysical experiment CELEBRATION 2000.

The biozonal standard for Polish sequences of the Silurian deposits is the graptolite scheme established around the beginning of the twentieth century for the classic British exposures (Elles, 1900; Wood, 1900; Elles and Wood, 1900, 1901–1918).

Later, the scheme became internationally accepted, and currently — with modifications proposed by, among others, Holland *et al*. (1963); Cocks *et al*. (1971) and Bassett *et al.* (1975) — is commonly used as a standard biostratigraphic framework.

Subdivision of the Silurian sequence in Poland are based on graptolites. The graptolite biostratigraphy mostly corresponds to the international standard scheme, though differences occur. These are largely in schemes created before 1990, mainly in those established by Tomczykowa and Tomczyk (1962–1990). Those authors used their own, essentially informal biostratigraphy, which different from the international standard as regards:

— the lower and upper boundaries of the system;

— the extent and position of boundaries of standard series and stages;

— the understanding of chrono-, litho- and biostratigraphic units *sensu* Hedberg (1976), and their mutual time-spatial relationships;

— the criteria by which stratigraphic units were classified and named;

— the ranges of many graptolite zones;

— the global correlation of marker horizons.

According to accepted international criteria the boundaries of the Silurian deposits in Polish sections are placed as follows: lower boundary (Ordovician/Silurian) — at the base of the *Akidograptus acuminatus* Zone (or the *Akidograptus ascensus* Zone of Teller which is almost exactly at the same level), and the upper boundary (Silurian/Devonian) — at the top of the *Monograptus transgrediens* Zone (Table 1).

NIDA REGION

In the Nida region Silurian deposits have been penetrated by four boreholes: Jaronowice IG 1, Książ Wielki IG 1, Włoszczowa IG 1 and Strożyska 5 (Fig. 1).

Palaeontologically dated Silurian deposits have been reported from the Jaronowice IG 1, Książ Wielki IG 1 (Jaworowski *et al*., 1967; Jurkiewicz, 1975) and Strożyska 5

Table 1

Silurian bio- and lithostratigraphy of the Holy Cross Mts.

CHRONOSTRATIGRAPHY			BIOSTRATIGRAPHY		HOLY CROSS MTS. GRAPTOLITES ZONES Teller (1995)	LITHOSTRATIGRAPHY Tomczyk (1962-1970)			LITHOSTRATIGRAPHY and BIOSTRATIGRAPHY Tomczykowa (1988)			LITHOSTRATIGRAPHY Teller (1997)	
SYSTEM	SERIES	STAGE	BIOZONES Graptolites	Conodonts		Łysogóry region	Kielce region centre	Kielce region Zbrza	Formations	Holy Cross Mts. graptolites zones	Lithology	Łysogóry region	Kielce region (NW)
D	D_1	Lochkovian	*Monograptus uniformis*	*Icriodus woschmidti woschmidti*		RZEPIN BEDS >500? m	LIPNICZEK SILTSTONE 50-150? m		RZEPIN	*agnustidens ? samsonowiczi ultimus*	GREYWACKES AND SILTSTONES	RZEPIN FM. T - 800-2000 m S - 400-500 m	KIELCE FM. M - ~500 m S - ~250 m
S I L U R I A N	PRIDOLI S_4		*Monograptus transgrediens* *Monograptus parultimus*	*Ozarkodina remscheidensis eosteinhornensis*	*transgrediens*								
	LUDLOW S_3	Ludfordian	*Bohemograptus*	*Ozarkodina crispa*	?	WYDRYSZÓW BEDS ~ 1500-2000 m	NIEWACHLÓW GREYWACKES 2000-500? m		WYDRYSZÓW	*dubius frequens tomczyki haupti*		WYDRYSZÓW FM. ?	NIEWACHLÓW FM. M - ~1200 m S - ~200-300 m
			Saetograptus leintwardinesis	*Ozarkodina snajdri*	*Bohemograptus aversus=leintwardinensis*								
		Gorstian	*Pristiograptus tumescens* *Saetograptus incipiens*	*Ancoradella ploeckensis*	*hemiaversus invertus*					*Bohemograptus*			
			Lobograptus scanicus		*scanius parascanius progenitor nilssoni*	WILKÓW SHALES ~ 200-250 m	PRĄGOWIEC BEDS 100-200 m		PRĄGOWIEC	*leintwardinensis hemiaversus pazdroi scanicus progenitor nillsoni colonus spinosus gotlandicus dubius ludennsis nassa*	GRAPTOLITE SHALES		
			Neodiversograptus nilssoni										
	WENLOCK S_2	Homerian – Gleedon	*Monograptus ludensis*	*Ozarkodina bohemica bohemica*	*ludensis* brak dokładnego podziału *nassa* *lundgreni*								
			Cyrtograptus nassa										
		Homerian – Whitwell	*Cyrtograptus lundgreni*										
		Sheinwoodian	*Cyrtograptus ellesae*	*Ozarkodina sagitta sagitta*	*ellesae* *rigidus belophorus=flexilis antennularius riccartonensis murchisoni centrifugus*	UPPER CIEKOTY SHALES 60-80 m	UPPER BARDO BEDS 60-80 m	UPPER ZBRZA SHALES 60-75 m	BARDO	*testis lundgreni multiramis perneri ellasae rigidus*		GRAPTOLITE SHALE FM. T - 250-350 m S - 290-250 m	GRAPTOLITE SHALE FM.
			Monograptus flexilis										
			Cyrtograptus rigidus										
			Monograptus riccartonensis							*flexilis symetricus dubius latus riccartonensis murchisoni insectus*			
			Cyrtograptus murchisoni	*Ozarkodina sagitta rhenana*									
			Cyrtograptus centrifugus										
	LLANDOVERY S_1	Telychian	*Monoclimacis crenulata*	*Pterospathodus amorphognathoides*	*grandis spiralis tullbergi griestoniensis crispus turriculatus linnaei*	DĘBNIAK BEDS 30-40 m	MIDDLE BARDO BEDS 20-40 m		DĘBNIAK	*grandis spiralis crenulata griestoniensis crispus turriculatus distans sedgwicki cometa*			
			Monoclimacis griestoniensis										
			Monograptus crispus	*Pterospathodus celloni*									
			Monograptus turriculatus										
		Aeronian	*Monograptus sedgwicki*	*Distomodus staurognathoides*	*sedgwicki convolutus simulans=magnus pectinatus*	LOWER CIEKOTY SHALES ~ 15-20 m	LOWER BARDO BEDS ~ 10-25 m	LOWER ZBRZA SHALES ~ 15-25 m	ZBRZA	*gregarius argentenus revolutus*			
			Monograptus convqlutus										
			Coronograptus gregarius – *argentus*										
			Coronograptus gregarius – *magnus*	*Distomodus kentuckyensis*						*triangulatus vesiculosus cyphus*			
			Coronograptus gregarius – *triangulatus*		*triangulatus*								
		Rhuddanian	*Coronograptus cyphus* – *cyphus*		*cyphus vesiculosus acuminatus ascensus*					*modestus accuminatus ?*			
			Coronograptus cyphus – *acinaces*										
			Cyrtograptus vesiculosus atavus										
			Akidograptus acuminatus										

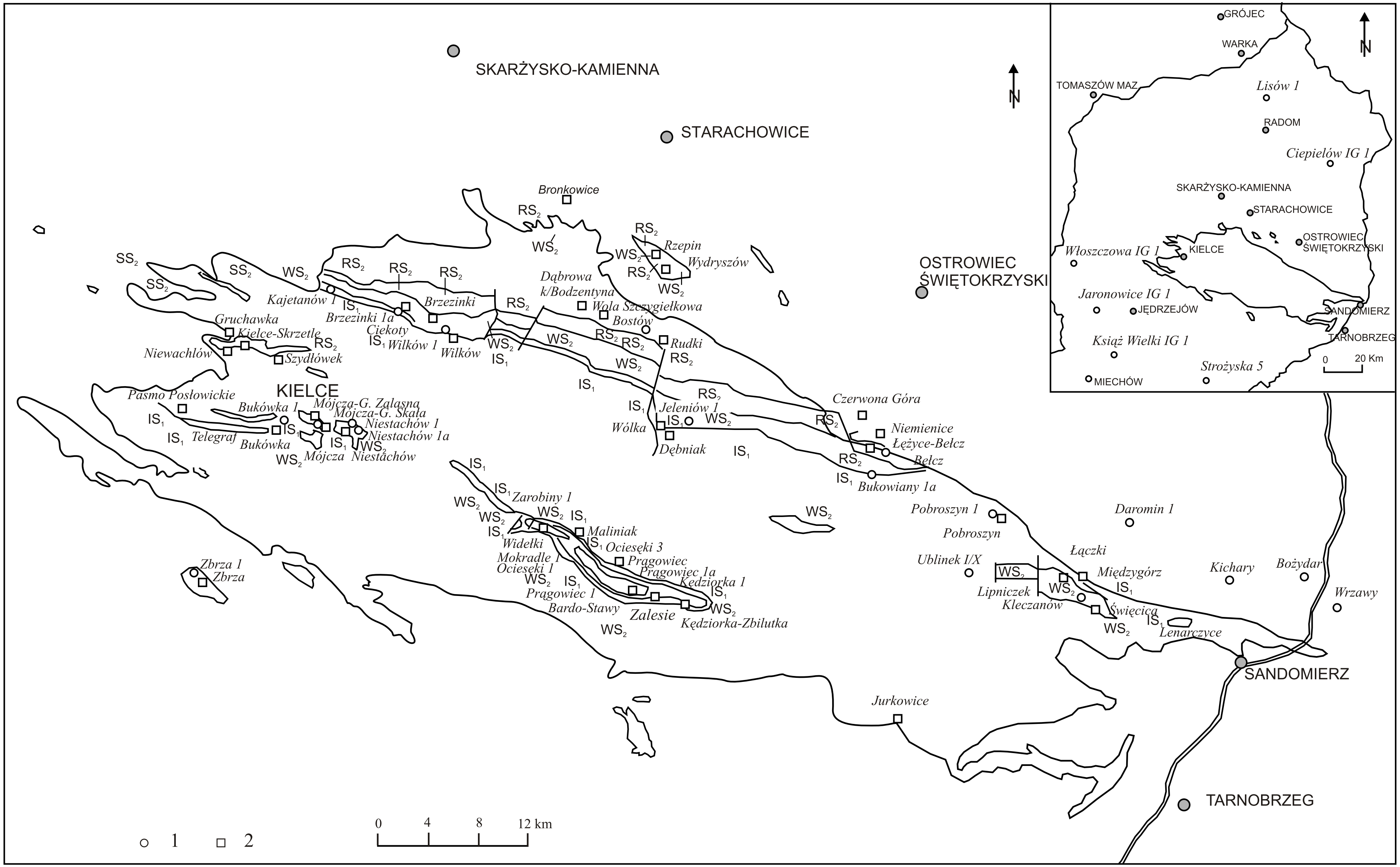

Fig. 1. Location map of boreholes and natural exposures of Silurian deposits in the Nida, Holy Cross Mts. and Radom areas

1 — boreholes reaching the unit analysed with thickness given in metres; 2 — exposures of the unit analysed with thickness given in metres

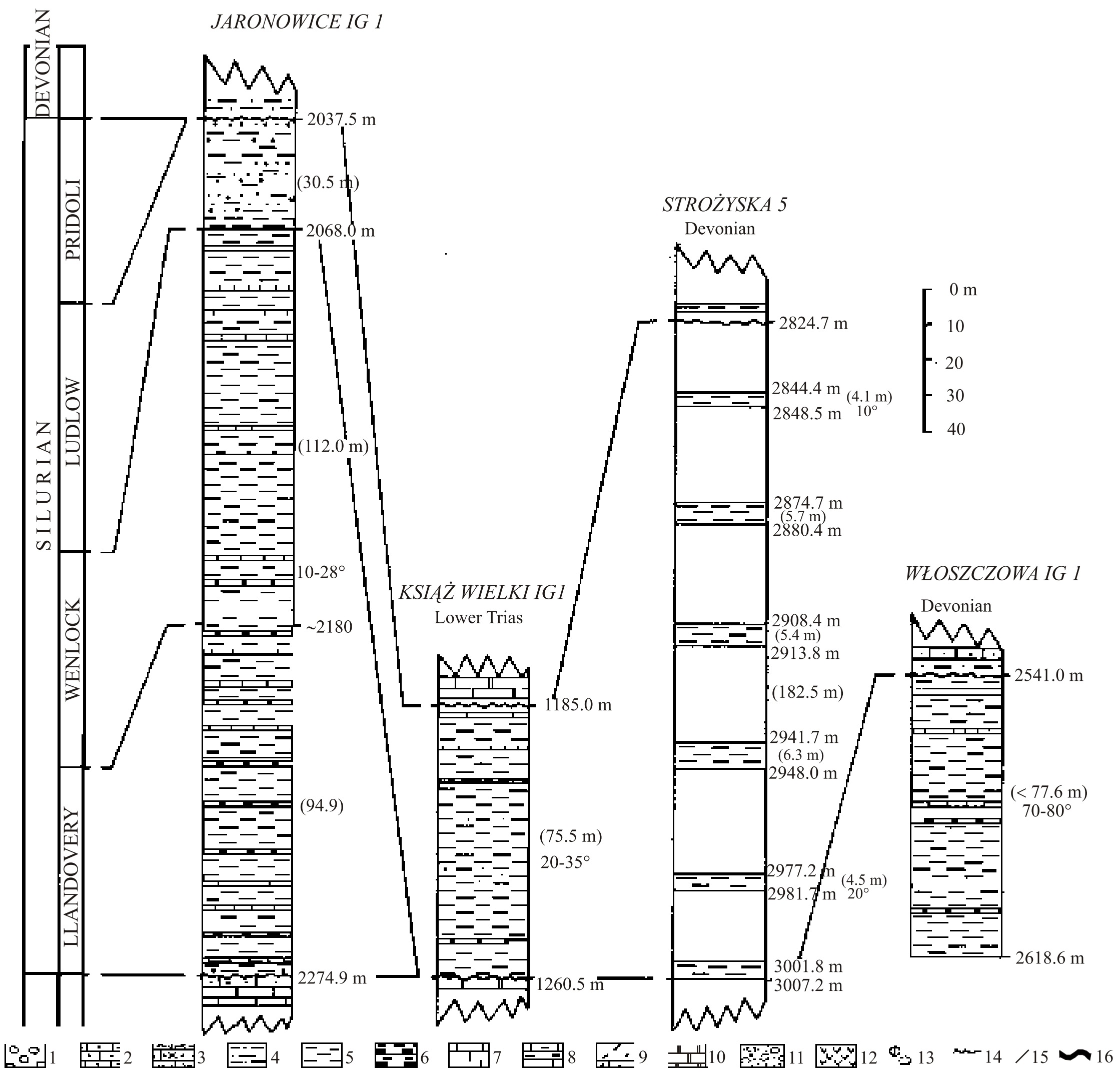

Fig. 2. Correlation chart of Silurian sections in the Nida area

1 — conglomerates; 2 — sandstones; 3 — greywacke sandstones; 4 — siltstones; 5 — claystones; 6 — siliceous shales and lydite interbeds; 7 — limestones; 8 — marly limestones; 9 — detrital limestones; 10 — dolomites; 11 — weathering mantle, till and sand; 12 — diabases; 13 — limestone lenses; 14 — erosional unconformities; 15 — faults; 16 — intervals non-represented

boreholes (Bednarczyk *et al*., 1968). The Włoszczowa IG 1 section is assigned to the Silurian on the basis of indirect evidence (Jurkiewicz, 1975).

Silurian deposits unconformably overlie Ordovician rocks, and at the top they are erosionally truncated and overlain by Lower Devonian (Emsian) or Lower Triassic deposits (Fig. 2). Dips of Silurian strata vary from 10–20° (Strożyska 5 and Książ Wielki IG 1 boreholes) up to 70–80° (Włoszczowa IG 1 borehole).

LITHOLOGY

No lithostratigraphy has yet been established for the fragmentary Silurian succession in the Nida area. The lithological succession comprises:

Llandovery. Llandovery deposits are known from the Jaronowice IG 1 borehole and probably from the Włoszczowa IG 1 borehole (Jurkiewicz, 1975, 1976). They are represented by dark grey and black, locally more or less silicified, laminated graptolitic clayey shales with subordinate interbeds of grey organodetrital limestones, marly and dolomitic limestones and dark grey lydites (cherts) as well as thinly bedded fine-grained sandstones. Their preserved apparent thickness ranges from 77.6 m in the Włoszczowa IG 1 borehole to approximately 108.5 m in the Jaronowice IG 1 borehole (Fig. 2).

Wenlock. Wenlock deposits were distinguished in the Jaronowice IG 1 borehole (depth 2068–2180? m) in a continuous Llandovery-Wenlock sequence. They are overlain by a clastic series considered to represent either the Upper Silurian (Ludlow) or Lower Devonian (Bednarczyk *et al*., 1968). These deposits are composed mainly of dark grey and grey clayey shales with episodic thin intercalations of dolomitic limestones, fine-grained sandstones and lydites.

Ludlow. The Ludlow series was penetrated by the Książ Wielki IG 1 (depth 1187.0–1260.5 m) and probably the Jaronowice IG 1 (depth 2037.5–2068.0 m) boreholes. The former section (Jaworowski *et al*., 1967; Jurkiewicz, 1975, 1976) comprises, up to a depth of 1240.1 m, black clayey shales showing thick platy partings, and containing muscovite and abundant graptolites. Above, up to a depth of 1209 m, there are dark grey and black clayey shales with rare fragments of graptolites. At the top the section is represented by a series of dark grey and greenish clayey shales containing no graptolites (depth 1187.0–1202.6 m) (Fig. 2).

Presumed Ludlow deposits in Jaronowice IG 1 borehole (Fig. 2) are mostly grey and grey-green unfossiliferous siltstones intercalated with conglomerates and thinly bedded fine-grained sandstones. Their Late Silurian age (Jurkiewicz, 1975) is inferred from their position in the profile and from lithological comparisons with presumed coeval equivalents in a greywacke facies in the Holy Cross Mts. area (Tomczyk, 1962*a*).

BIOSTRATIGRAPHY

Llandovery. The only Llandovery section that yields abundant graptolite fragments comes from the Jaronowice IG 1 borehole. The graptolites prove the early Llandovery age of deposits in the lower part of the section (depth 2270.0–2274.9 m). Jaworowski identified the following graptolites: *Climacograptus scalaris normalis* Lapworth, *Climacograptus* ex gr. *scalaris* (Hisinger), *Pristiograptus* sp. indet. and *Neodiversograptus* sp. indet. No guide graptolites have been found in the upper part of the series.

Wenlock. Wenlock deposits are known only from the Jaronowice IG 1 borehole (depth 2068–2180 m). The middle and upper part of the sequence is well documented palaeontologically (approximate depths 2080.0–2169.0 m). The graptolite assemblage identified by Jaworowski includes, among others, *Cyrtograptus lundgreni* Tullberg, *Cyrtograptus hamatus* (Baily), *Cyrtograptus* cf. *perneri* (Boucek), *Cyrtograptus* ex gr. *rigidus* Tullberg, *Cyrtograptus ellesae* Gortani, *Monograptus testis testis* (Barrande), *Monograptus flexilis* Elles, *Monograptus flemingi* (Salter), *Monograptus flumendosae* (Gortani), *Monoclimacis hemipristis* (Meneghini) (Jaworowski *et al*., 1967). These forms univocally indicate a Wenlock (Homerian) age for this section represented by three graptolite zones of *Monograptus flexilis*, *Monograptus perneri* and *Cyrtograptus lundgreni-Monograptus* (*Testograptus*) *testis* (Jaworowski *et al*., 1967; Jurkiewicz, 1975, 1976). The lower parts of the presumed Wenlock section have yielded no graptolites (Jurkiewicz, 1975, 1976).

Ludlow. Palaeontologically dated Ludlow deposits are known from the Książ Wielki IG 1 (depth 1185.0–1260.5 m) and Strożyska 5 (depth 2824.5–3007.2 m) boreholes. A succession from the Jaronowice IG 1 borehole (depth 2037.5–2068.0 m), included within the Upper Silurian sequence, is also probably of Ludlow age.

The Książ Wielki IG 1 borehole has yielded graptolite fragments within the interval of 1202.6–1245.0 m. The graptolite assemblage is represented here by *Lobograptus scanicus* Tullberg, *Neodiversograptus nilssoni* (Lapworth), *Neodiversograptus* cf. *nilssoni* (Lapworth), *Neodiversograptus* sp. and *Pristiograptus* sp. indet., indicating the presence of the Lower Ludlow *Neodiversograptus nilssoni-Lobograptus scanicus* Zone (Jaworowski *et al*., 1967).

Palaeontologically dated deposits are also represented in the Strożyska 5 borehole at depths of 2824.7–3007.8 m. They are very well dated within the interval of 2824.5–2981.9 m by abundant graptolite taxa and represent the Lower Ludlow *Neodiversograptus nilssoni* Zone. Graptolites are represented here by, among others, *Neodiversograptus nilssoni* (Lapworth), *Saetograptus chimera* (Barrande), *Pristiograptus bohemicus* (Barrande), *Pristiograptus dubius* (Suess), *Lobograptus* sp., *Plectograptus macilentus* (Tornquist), *Spinograptus spinosus* (Wood), *Monograptus uncinatus* (Tullberg) and *Colonograptus colonus* (Barrande).

No faunal remains have been found in Silurian deposits from depths of 3001.0–3007.2 m. However, according to Teller (In: Bednarczyk *et al.*, 1968), this interval is represented by Lower Ludlow (Gorstian) deposits.

Unfossiliferous clastics from the uppermost part of the Silurian section in the Jaranowice IG 1 borehole (depth 2037.0–2068.0 m), (Jurkiewicz, 1975) may also represent the Upper Silurian (?Ludlow), though Teller, thought them to be Lower Devonian (Bednarczyk *et al.*, 1968). The lithological and graptolitic succession in the Silurian sections of the Nida area — particularly in the Jaronowice IG 1 borehole — are most similar to Silurian sequences from the Zbrza Anticline (the “Southern Region”) in the south of the Kielce region. Lower Ludlow deposits from the Strożyska 5 borehole correlate with Lower Ludlow rocks exposed in the southern Holy Cross Mts., representing the same facies with an identical graptolite succession (Bednarczyk *et al*., 1968).

HOLY CROSS MTS. — ŁYSOGÓRY REGION

In the Palaeozoic rocks of the Holy Cross Mts., Silurian deposits have been recognised since the mid-nineteenth century (Zejszner, 1868, 1869; Gürich, 1896; Siemiradzki, 1922). However, their stratigraphy was established much later by Samsonowicz (1916, 1928, 1934) and Czarnocki (1919, 1936, 1950, 1957). Further contributions were made by Tomczyk (1954, 1956, 1968, 1974), Tomczykowa (1959, 1988, 1990), Pawłowska (1961), Tomczykowa and Tomczyk (1962, 1981), Deczkowski (1963), Filonowicz (1971, 1973) and Kowalczewski (1971) and, more recently, by Malec (1988, 1989, 1991, 1993), Przybyłowicz and Stupnicka, (1989), Romanek and Rup (1989), Woźniak (1989), Stupnicka *et al.* (1991).

The uplifted Palaeozoic core of the Holy Cross Mts. is divided into two structurally different geological regions — the Kielce region in the south, and Łysogóry region in the north. Silurian sequences of these areas differ in their stratigraphic sedimentary and tectonic development. These two regions are separated by the Main Fault, also known as the Holy Cross Fault (Czarnocki, 1919, 1957).

The Silurian deposits of the Łysogóry region are known from the following natural exposures and boreholes (Fig. 1): Kajetanów 1 (depth 19.0–255.2 m), Brzezinki 1a, Ciekoty, Wilków, Wilków 1 (depth 6.0–601.0 m), Dąbrowa near Bodzentyn, Wola Szczygiełkowa, Bronkowice, Rzepin, Wydryszów, Bostów, Bostów 61892 borehole, Rudki, Wólka, Dębniak, Jeleniów 1 (depth 15.5–61.0 m), Bukowiany 1a (depth 22.6–106.0 m), Czerwona Góra, Niemienice, Łężyce- Bełcz, Bełcz 61895 borehole, Pobroszyn, Pobroszyn 1 (depth 10.0–125.3 m), Kichary (depth ?–127.5 m), Daromin (depth ?– 39.1 m), Wrzawy (depth 200.5–360.9 m), Bożydar.

They are characterised by a continuous marine facies with no significant gaps and a continuous transition into the Lower Devonian. The facies, northward dipping pattern of the deposits and continuous transition into Devonian rocks indicate a direct palaeogeographical connection with the foreland of the East European Platform (Stupnicka *et al.*, 1991).

LITHOSTRATIGRAPHY

The thick Silurian deposits show little lithological variation vertically or laterally. Two main lithological units can be distinguished (Czarnocki, 1950, 1957). These are dark coloured shales with graptolites in the Llandovery to Lower Ludlow, and a greywacke-shale facies in the Upper Ludlow to Pridoli (Table 1).

A composite lithological profile of the Łysogóry region has been compiled from individual exposures and borehole sections, which, though, may not represent the whole sequence (Fig. 3). Usually, it is impossible to determine precisely thicknesses of particular units or define their boundaries. Tomczyk (1962*a*, *b*, 1968) proposed a lithostratigraphic subdivision of this section, though his scheme (Table 1) needs revising in the light of the formal criteria recommended in the Polish Code of Stratigraphic Classification, Nomenclature and Terminology (1975).

Teller's stratigraphy begins with the Lower Ciekoty Shales penetrated by the Wilków 1 and Jeleniów 1 boreholes. These are black siliceous shales, approximately 15–20 m thick, included within the Lower Llandovery.

Above, the Dębniak Beds separate the Lower and Upper Ciekoty Shales. They are composed of greenish dolomitic-calcareous siltstones and claystones with thin intercalations of black bituminous shales (Tomczyk, 1968) assigned to the upper Llandovery. Their thickness ranges from 30 to 40 m.

Next unit, the Upper Ciekoty Shales, is represented by dark grey clayey and siliceous shales. These are considered to be Wenlock in age, and their thickness varies from 60 to 80 m.

The Upper Ciekoty Shales are overlain by the Wilków Beds known from the Wilków 1 and Bukowiany 1a boreholes, as well as from the Ciekoty, Jeleniów and Pobroszyn exposures. This unit is composed of grey and grey-greenish clayey and siliceous shales with marly and calcareous interbeds and lenses in the lower part, and laminated siltstones and local greywackes higher in the succession. The Wilków Beds are assigned to the lower Ludlow and their estimated thickness ranges from approximately 200 to 250 m (Tomczykowa and Tomczyk, 1981).

Czarnocki (1950, 1957) distinguished two regional stages within the Silurian greywacke-shale sequence of the Łysogóry area: the Wydryszów and Rzepin stages. Their rank was later changed by Tomczyk (1962*a*, *b*), who introduced the terms Wydryszów and Rzepin Beds.

The Wydryszów Beds are represented by grey-greenish and olive clayey and sandy shales and greywackes. These beds are exposed in a series of exposures stretching along a narrow belt from Kajetanów through Nowa Słupia to Pobroszyn, and northwards in the Wydryszów and Bronkowice exposures. Their upper boundary with the overlying Rzepin Beds is not well defined. The thickness of the Wydryszów Beds is estimated to range approximately from 1500 to 2000 m (Tomczyk, 1962*a*; Tomczykowa and Tomczyk, 1981).

The Rzepin Beds are divided into the lower and upper parts (Tomczykowa and Tomczyk, 1981). The Lower Rzepin Beds are represented largely by claystones and siltstones with sandstone and greywacke interbeds. The Upper Rzepin Beds are composed mostly of claystones. These rocks are usually olive-green in colour, but there are also variegated and red parts. They are known from exposures situated at Łężyce-Bełcz, Niemienice, Czerwona Góra, Rudki and near Rzepin and Bronkowice. The Rzepin Beds are considered to be Pridoli in age (Table 1). Their thickness is undetermined and, locally, may probably exceed 500 m (Tomczyk, 1962*a*).

BIOSTRATIGRAPHY

The basis of the biostratigraphic scheme was created before and just after the Second World War by Czarnocki and Samsonowicz. Later, the Silurian biostratigraphy was studied by Pawłowska (1961), Deczkowski and Tomczyk (1969), Kowalczewski (1971*a*), Tomczyk (1957–1990) and Tomczykowa (1959–1991).

Llandovery. This series was penetrated by the boreholes Kajetanów 1, Brzezinki, Wilków 1, Dębniak and Jeleniów 1. The biostratigraphic zonation of the Llandovery section (Table 1) based on graptolites (Tomczykowa and Tomczyk, 1981), comprised 11 zones and 4 subzones.

A comparison with the stratigraphy in Harland *et al*. (1989) shows that the zonation created by Tomczyk and Tomczykowa includes most of the zones recognised globally. The only zone lacking is that of *Monograptus convolutus*. Two subzones lacking are also: *acinaces* within the *Coronograptus cyphus* Zone, and *magnus* within the *Coronograptus gregarius* Zone. Analyses of archival materials (Tomczyk, 1957, 1968, 1990, Deczkowski and Tomczyk, 1969) show that some of the zones seem not to have been reliably documented. For instance, the published evidence of the *Coronograptus cyphus* and *Coronograptus gregarius* Zones is slight. Of index taxa for Llandovery zones, only the species *Monograptus crispus* Lapworth has been described and illustrated (Tomczyk, 1990).

Wenlock. This series has been studied between Kajetanów and Jeleniów. The most complete and best palaeontologically documented sections are from the Wilków 1, Kajetanów 1 and Jeleniów 1 boreholes as well as in exposures at Ciekoty, Kajetanów and Wólka (Fig. 1).

In the lower Wenlock Tomczykowa and Tomczyk (1981) distinguished 10 graptolite zones beginning with the

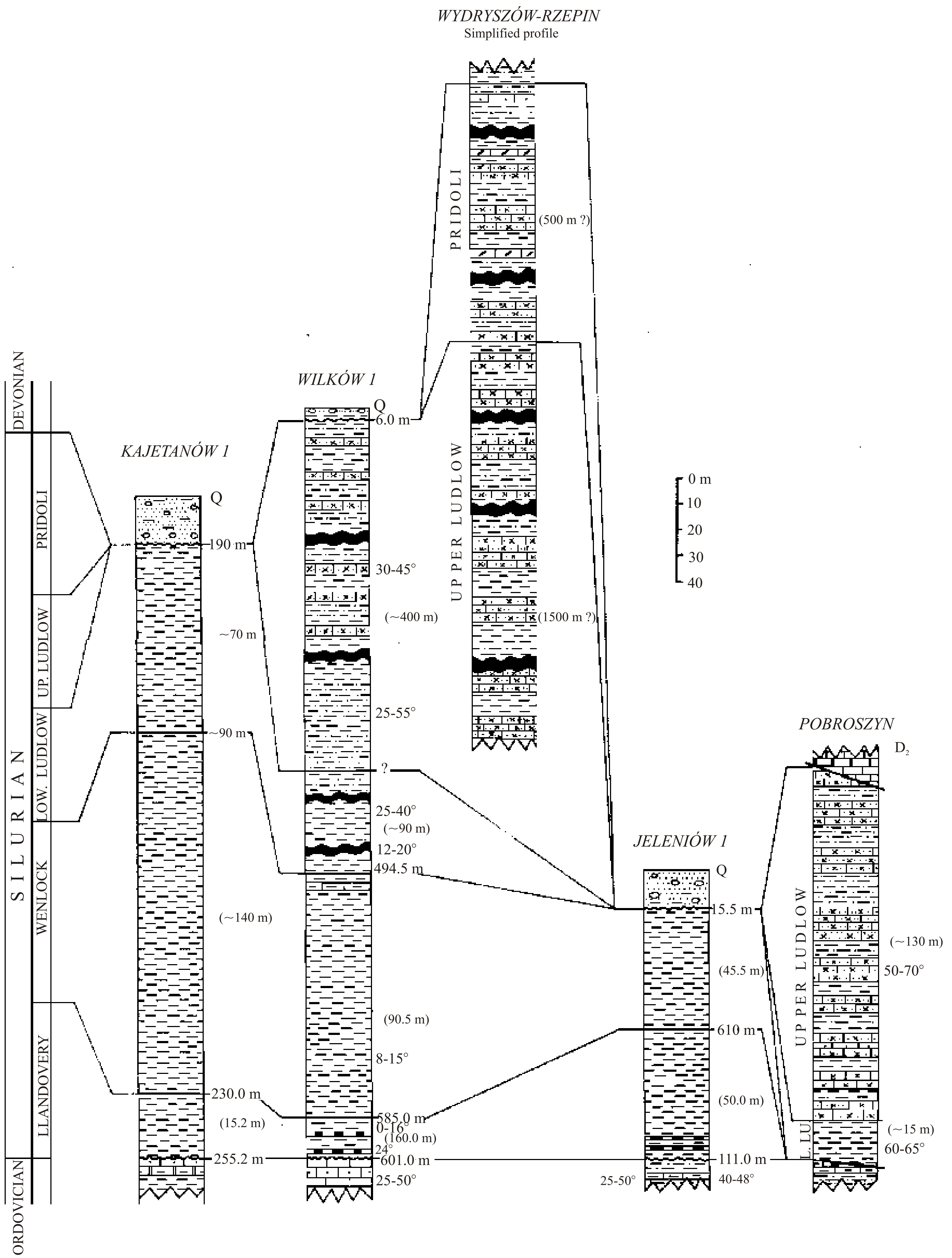

Fig. 3. Correlation chart of Silurian sections in the Łysogóry region

For explanations see Figure 2

Cyrtograptus insectus Zone up to the *Cyrtograptus multiramis* Zone. The following global zones are included within this succession: *Cyrtograptus murchisoni*, *Monograptus riccartonensis, Cyrtograptus rigidus*, *Monograptus flexilis* and *Cyrtograptus ellesae*. Thus, the lowermost *Cyrtograptus centrifugus* Zone is the only one lacking, being replaced by the *Cyrtograptus insectus* Zone.

However, the palaentological basis for these zones, other than those of *Cyrtograptus murchisoni* and *Cyrtograptus rigidus*, has not been published (Tomczyk, 1957, 1962*a*, *b*, 1968, 1990; Deczkowski and Tomczyk, 1969; Tomczykowa and Tomczyk, 1981).

Globally, the upper Wenlock typically includes three biostratigraphic zones (e.g. Harland *et al*., 1989), those of *Cyrtograptus lundgreni, Gothograptus nassa* and *Monograptus ludensis*. Tomczykowa and Tomczyk (1981) proposed, for the Holy Cross Mts., an additional *Testograptus testis* Zone between the *Cyrtograptus lundgreni* and *Gothograptus nassa* Zones (they included, though, the *Gothograptus nassa* and *Monograptus ludensis* Zones within the lower Ludlow).

The *Cyrtograptus lundgreni* and *Gothograptus nassa* Zones are well documented by the presence of index taxa (Tomczyk, 1957, 1962*a, b*, 1990; Dulski and Zagórski, 1962; Deczkowski and Tomczyk, 1969). The *Monograptus ludensis* Zone, termed the *Pristiograptus vulgaris* Zone in older papers (e.g. Tomczykowa and Tomczyk, 1962; Deczkowski and Tomczyk, 1969), possesses no such documentation.

Ludlow. The composite section of the lower Ludlow consists of five graptolite zones and two subzones (Tomczykowa and Tomczyk, 1981), of which those of *Neodiversograptus nilssoni* and *Lobograptus scanicus* Zones are of global rank. They are relatively well documented by both specimens of index taxa and other guide graptolites, and have been identified at the Ciekoty exposures (Tomczyk, 1968) as well as in the Wilków 1 borehole (Deczkowski and Tomczyk, 1969) and others (e.g. Dulski and Zagórski, 1962; Tomczyk, 1968).

In the uppermost lower Ludlow (Gorstian), the *Saetograptus incipiens* and *Pristiograptus tumescens* Zones of global rank are replaced in this area by the approximately coeval *Cucullograptus pazdroi* and *Cucullograptus hemiaversus* Zones (Tomczykowa and Tomczyk, 1981). The *Cucullograptus hemiaversus* Zone has been recognised beyond the Holy Cross Mts., as far as the Polish Lowlands (Urbanek and Teller, 1977), while the *Cucullograptus pazdroi* Zone is of only local significance. Both the lower (*Saetograptus leintwardinensis* Zone) and the upper part (the broadly defined *Bohemograptus* Zone — Harland *et al*., 1989) of the upper Ludlow (Ludfordian) were documented in this area by an assemblage of guide graptolites (Tomczyk, 1968; Deczkowski and Tomczyk, 1969; Tomczykowa and Tomczyk, 1981). However, according to Tomczyk and Tomczykowa (1981), only the *Saetograptus leintwardinensis* Zone represents the upper Ludlow, overlying deposits belonging to the Siedlce series. Within the time span corresponding to the upper Ludfordian *Bohemograptus* Biozone (Harland *et al*., 1989), Tomczyk (1990) distinguished 6 graptolite zones, and yet higher in the succession further three zones of *Monoclimacis haupti*, *Monoclimacis tomczyki* and *Pristiograptus dubius frequens* (Tomczykowa and Tomczyk, 1981). According to Tomczykowa and Tomczyk this part of the section corresponds to the lower and middle Siedlce[1].

Pridoli. The Pridoli of the Łysogóry region is represented by the Rzepin Beds which were studied e.g. in the vicinity of Rzepin, Łeżyce-Bełcz and Czerwona Góra (Tomczykowa and Tomczyk, 1981). These deposits have yielded trilobites (Tomczykowa, 1962), corals (Różkowska, 1962), rare brachiopods and bivalves and very scarce graptolites.

The most important trilobites in the Rzepin Lower Beds are *Acastella spinosa* (Salter), *Proetus signatus* Lindstrom and *Homalonotus knighti* Konig recognised also from Pridoli deposits of NE Poland, Podolia, Great Britain and other areas.

The Upper Rzepin Beds contain, according to Tomczykowa and Tomczyk (1981), rare graptolites: *Pristiograptus samsonowiczi* Teller, *Monoclimacis ultimus* (Perner) and *Monograptus angustidens* Pribyl. *Monoclimacis ultimus* (Perner) is an index taxon of global significance within the lower Pridoli (Teller, 1990). *Pristiograptus samsonowiczi* Teller defines a zone within the lower Pridoli of eastern Poland and Volhynia. *Monograptus angustidens* Pribyl is a guide species — according to the international standard scheme — in the Lower Devonian. Correspondingly, the upper part of the Upper Rzepin Beds should be correlated with the Lower Devonian (Gedinnian).

The Upper Rzepin Beds also contain the trilobite *Acaste dayiana* Richter et Richter (Tomczykowa, 1990) characteristic of the lower Pridoli. It occurs in deposits of the *Monograptus ultimus-Pristiograptus samsonowiczi* Zones of Poland and other European areas.

HOLY CROSS MTS. — KIELCE REGION

Silurian deposits are known from the following natural exposures and boreholes of the Kielce region (Figs. 1 and 4): Zbrza, Zbrza 1 (depth 0.0–9.5 m), Niewachlów, Gruchawka, Kielce-Skrzetle, Szydłówek, Pasmo Posłowickie, Telegraf (northern slope), Bukówka, Bukówka 1 (depth 3.0–26.6 m), Mójcza-Góra Skała, Mójcza-Góra Zalasna, Mójcza 1 (depth 16.5–63.8 m), Niestachów, Niestachów 1 (depth 46.2–5.5 m), Niestachów 1a (depth 2.0–36.2 m), Zarobiny 1 (depth 15.1–132.0 m), Widełki, Maliniak, Mokradle 1 (depth 5.0–179.4 m), Ociesęki 1 (depth 4.0–25.1 m), Ociesęki 3 (depth 4.0–13.0 m), Prągowiec, Prągowiec 1 and 1a, Bardo-Stawy, Zalesie near Łagów, Kędziorka 1 (depth 11.6–274.3 m), Kędziorka-Zbilutka, Jurkowice, Ublinek I/X (depth 34.4–100.0 m and 10.0–26.2 m), Lipniczek, Łączki,

[1]The Silurian sequence of the Precambrian Craton was divided by Tomczyk (1990) into the following five informal regional series: Pasłęk, Bielsk, Mielnik, Siedlce and Podlasie. Four of them are subdivided into lower and upper parts (Pasłęk, Bielsk, Mielnik and Podlasie). The Siedlce series is subdivided into lower, middle and upper parts. These regional units sensu Tomczyk correspond to the following series of the standard scheme: Pasłęk = Llandovery, Bielskian = Wenlock, Mielnik + lower and middle Siedlce = Ludlow, upper Siedlce + Podlasie = Pridoli.

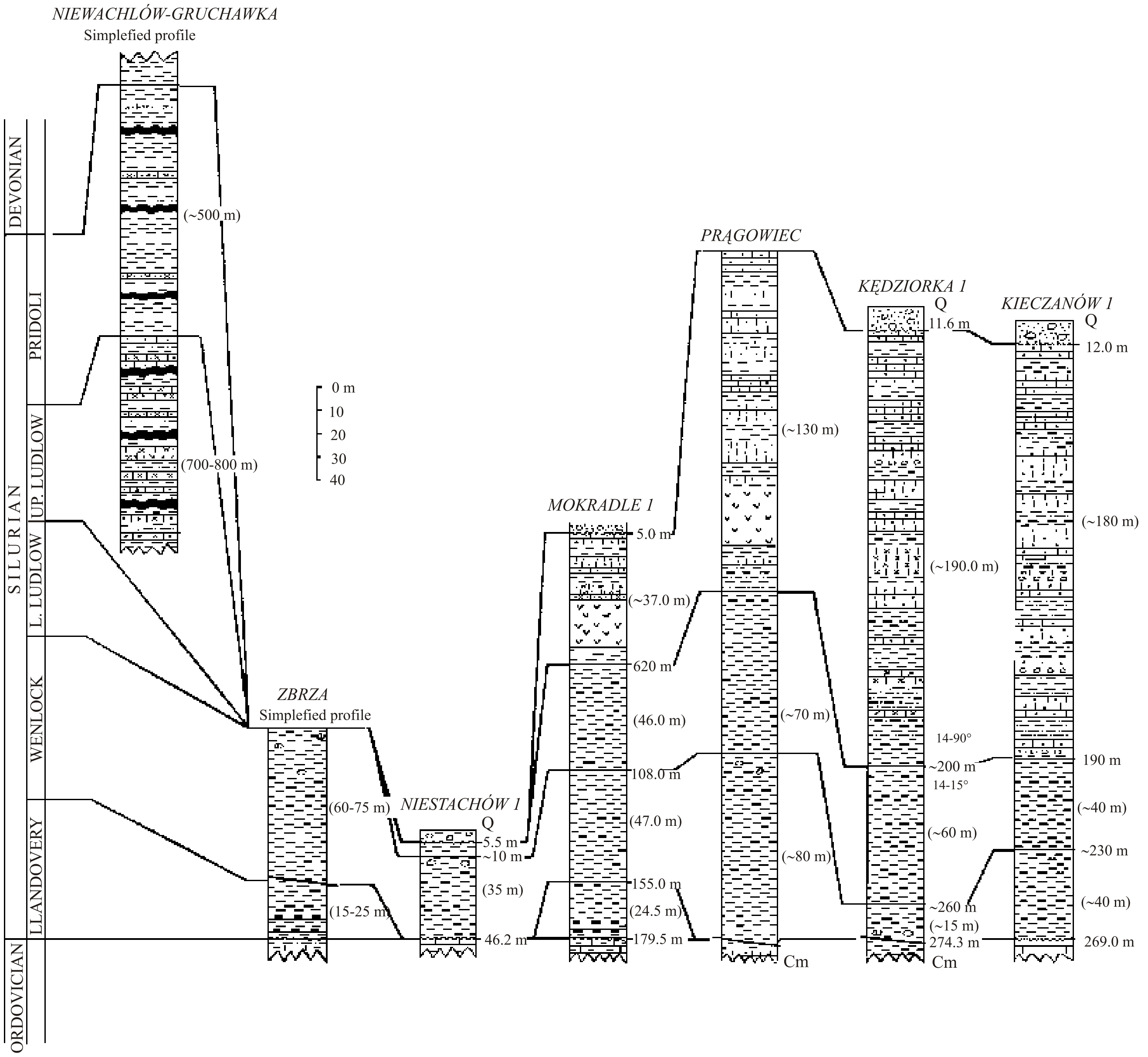

Fig. 4. Correlation chart of the Silurian sections in the Kielce region

For explanations see Figure 2

Międzygórz, Kleczanów 1 (depth 12.0–269.0 m), Święcica, Lenarczyce (depth 19.0–44.9 m).

The successions of this area show numerous sedimentary gaps spanning long time intervals, interpreted as evidence of the synorogenic Taconian tectonic episode in the lower part of the succession, and of the Ardenian episode in the upper part. The latest studies of Malec (1988, 1993) and Przybyłowicz and Stupnicka (1989) show that Silurian deposits of the Kielce region were most likely subjected to erosion after the Erian movements and are unconformably overlain by Siegenian or Emsian deposits.

LITHOSTRATIGRAPHY

Two areas can be distinguished within the Kielce region during the Silurian: the central and southwestern (Zbrza) area. Different lithostratigraphic schemes were suggested for them (Tomczyk, 1962*a*, *b*), though, these require formal amendment.

Only the lower part of the Silurian section, spanning the Llandovery and Wenlock, is known from the Zbrza area. This is represented by the Lower and Upper Zbrza Shales (Tomczyk, 1962 *a*, *b*; Deczkowski and Tomczyk, 1969).

The Lower Zbrza Shales comprise black bituminous clayey shales with thin intercalations of siliceous shales. These deposits occur in the Zbrza exposures and in the Zbrza 1 borehole. They are assigned to the lower Llandovery. Their incomplete thickness ranges from approximately 15 to 25 m (Deczkowski and Tomczyk, 1969).

The Lower Zbrza Shales are overlain with a stratigraphic gap by the Upper Zbrza Shales represented by grey-yellow, slightly calcareous claystones containing rare limestone concretions. Their thickness is estimated at 60–75 m.

In the central part of the Kielce region, the Silurian section begins with the Bardo Beds subdivided into lower, middle and upper parts (Tomczyk, 1962*a*; Tomczykowa and Tomczyk, 1981). This sequence is known from a series of exposures and a few boreholes, of which the most important are the Bardo-Stawy, Zalesie and Międzygórz boreholes.

The Lower Bardo Beds are composed of black siliceous shales with lydite interbeds. The graptolite fauna (Tomczyk, 1962*a*) indicates a lower Llandovery age. Their equivalents in the Zbrza area are the Lower Zbrza Shales, and, in the Łysogóry region, the Lower Ciekoty Shales.

The Middle Bardo Beds are represented mostly by claystones and siltstones, sandy in their lowermost part, passing upwards into greenish dolomitic-calcareous claystones with thin intercalations of black shales containing graptolites proving the presence of the upper Llandovery. This unit has no equivalent in the south of the Kielce region (Zbrza area), but in the Łysogóry region it corresponds to the Dębniak Beds.

The Upper Bardo Beds are composed of clay shales with graptolites. They pass upwards into calcareous claystones, often with lenses and concretions of limestones. This unit is assigned to the Wenlock, and its equivalent in the southern part of the Kielce region is the Upper Zbrza Shales, whereas in the Łysogóry region, it is the Upper Ciekoty Shales.

The total thickness of the Bardo Beds in this area varies from 80 to approximately 150 m (Tomczyk, 1962*a*).

Higher in the section are the Prągowiec Beds (Tomczyk, 1962*a*, 1968), most completely exposed in the classic section of the Prągowiec Gorge. The rocks are represented by calcareous clay shales and siltstones passing into dark grey clay shales with calcareous concretions (Kowalczewski and Migaszewski, 1994). Tomczyk (1962*a*) and Tomczykowa and Tomczyk (1981) included these beds into the lower Ludlow (Gorstian), though using current classification (Urbanek and Teller, 1997), they should be placed within the upper Wenlock-lower Ludlow. The Prągowiec Beds are usually 100–150 m thick, with maximum thicknesses up to 200 m (Tomczykowa and Tomczyk, 1981).

A change in sedimentation type is observed above the Prągowiec Beds, and clayey deposits with graptolites are replaced by a monotonous claystone-greywacke succession called the Niewachlów Greywackes (Czarnocki, 1936, 1957; Tomczyk, 1962*a*; Tomczykowa and Tomczyk, 1981; Kowalczewski, 1971*a*). A more detailed subdivision of this series is given by Malec (1993) who introduced the terms Niewachlów Beds for the lower and the Kielce Beds for the upper part of the section. In recent literature (Kowalczewski and Migaszewski, 1994) the Niewachlów Beds have been replaced by the term Niewachlów Formation.

The stratotype section of the Niewachlów Formation is represented by greywacke-claystone deposits (Malec, 1990, 1993). Most research workers assign them to the upper Ludlow (e.g. Tomczyk, 1962*a*, 1968; Malec, 1993; Kowalczewski and Migaszewski, 1994) considering them to be an equivalent to the Wydryszów Beds of the Łysogóry region. A different opinion was expressed by Stupnicka *et al*. (1991) who, after a stratigraphic analysis of the Widełki section, considered that this series had been deposited over a short time interval at the lower/upper Ludlow boundary. Different authors have estimated different thicknesses of this formation. Tomczyk (1962*a*), Romanek and Rup (1989) and Malec (1993) worked out considerable thicknesses of about 700–800 m, whereas according to Stupnicka, *et al*. (1991) the succession in the Widełki section is approximately 50 m thick.

The Kielce Beds are composed of dark grey claystones with rare interbeds of fine-grained greywacke sandstones. Sedimentary structures indicate that these are typical deep-marine turbidites (Malec, 1993, 1994). This sequence was studied in detail in stratotype sections situated in the NW sector of the city of Kielce. Some authors assign the sequence to the Pridoli as an equivalent of the Rzepin Beds of the Łysogóry region (Kowalczewski *et al.*, 1998). Others include it within the upper Ludlow (Tomczykowa, 1993). The thickness of these deposits are estimated at approximately 500 m. They grade upwards with sedimentary continuity into the overlying Klonów Beds (Pridoli/lower Gedinnian transition).

A slightly different development of the uppermost Silurian sequence of the central part of the Kielce region is present at Bardo (Stupnicka *et al*., 1991) and in the eastern area near Międzygórz (Tomczyk, 1962*a*).

At Bardo (Widełki section) the Niewachlów Greywackes are overlain in sedimentary continuity by the Widełki Shales (Przybyłowicz and Stupnicka, 1989; Stupnicka *et al*., 1991) represented by light grey clayey shales interbedded with sandstones and siltstones composed largely of pyroclastic material. A graptolite assemblage identified by Porębska shows that these deposits belong to the lower Ludlow and nearly all the upper Ludlow. In the stratotype section they are 8–10 m thick.

In the eastern part of the region, the Niewachlów Greywackes are overlain by the so-called Lipniczek Siltstones (Tomczyk, 1962*a*, *b*, 1968). The fossils show affinities to the fauna from the lower part of the Rzepin Beds, and therefore these siltstones may be of Pridoli age.

BIOSTRATIGRAPHY

Biostratigraphic studies have been conducted in this area since the mid-nineteenth century (Zejszner, 1868, 1869). Significant progress in geological exploration was observed after the First World War due to work by Czarnocki (1919–1939) and Samsonowicz (1916–1934). After the Second World War investigations were intensified and their results published, most fully by Tomczyk (1954–1990).

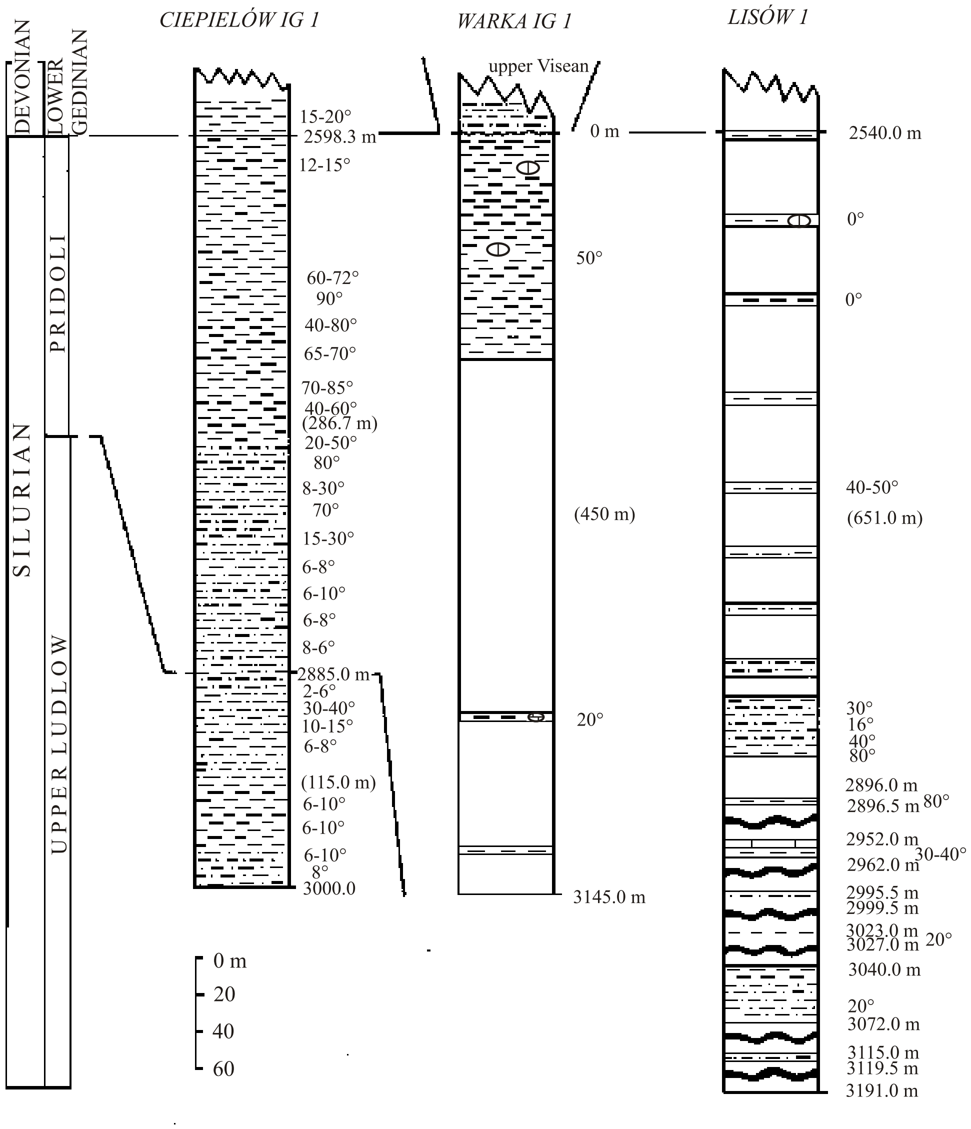

Fig. 5. Correlation chart of Silurian sections in the Radom area

For explanations see Figure 2

Llandovery. The most complete and best documented (by graptolites) lower Llandovery section is known from the vicinity of Zbrza (Tomczyk, 1962*a*, *b*, 1968; Deczkowski and Tomczyk, 1969). Graptolite zones of a global rank (Harland *et al*., 1989) were identified there starting from the *Akidograptus acuminatus* Zone, through the *Coronograptus cyphus* Zone to the *Coronograptus gregarius* Zone. Above, the lower Llandovery deposits are directly overlain by lower Wenlock rocks (Tomczyk, 1962*b*) and a considerable stratigraphic gap, probably resulting from a tectonic contact between deposits of different ages, is present.

In the central area, Llandovery deposits have been palaentologally dated e.g. in the type section of Bardo-Stawy as well as in nearby located Zalesie and Mokradle 1 sections (Tomczyk, 1962*a*, 1968). The three lowermost Llandovery zones of *Akidograptus acuminatus*, *Cystograptus vesiculosus* and *Coronograptus cyphus* were distinguished there within graptolitic shales. Above in the section, a shallowing of the basin and local sedimentary breaks are observed, manifested by sandy and conglomeratic interbeds. According to Tomczykowa and Tomczyk (1981) a stratigraphic gap spans the standard *Coronograptus gregarius* through *Monograptus crispus* Zones. The overlying deposits are again represented by shales containing an abundant fauna that documents the presence of the upper Llandovery *Monoclimacis griestoniensis* and *Monoclimacis crenulata* Zones of the standard scheme. Above them Tomczyk (1968) distinguished the younger zones of *Spirograptus spiralis* and *Stomatograptus grandis*.

The stratigraphic position of Llandovery deposits in the eastern area of the Kielce region, near Międzygórz, is unclear. Tomczyk (1954) identified in this section equivalents of the British graptolite zones from the *Coronograptus gregarius* Zone up to the *Monoclimacis crenulata* Zone. A rich assemblage of graptolites includes index taxa of the *Demirastrites triangulatus* Subzone (within the *Coronograptus gregarius*

Zone) and *Monograptus convolutus*, *M. sedgwicki*, *Monoclimacis griestoniensis* and *M. crenulata* Zones.

In later papers, giving no detailed explanations, the stratigraphical range of this section was restricted to the uppermost Llandovery (*Monoclimacis griestoniensis* and *M. crenulata* Zones), with the *Spirograptus spiralis* Zone distinguished above (Tomczyk, 1968; Tomczykowa and Tomczyk, 1981).

Wenlock. The lower Wenlock has a detailed zonation in the south of the region near Zbrza, in the central area at Bardo and in the east — near Międzygórz (Tomczyk, 1962*a*, *b*, 1968; Tomczykowa and Tomczyk, 1981). The lowermost zone of the British stratigraphy the *Cyrtograptus centrifugus* Zone, is replaced there by the *Cyrtograptus insectus* Zone. The other standard zones i.e. *Cyrtograptus murchisoni*, *Monograptus riccartonensis*, *Cyrtograptus rigidus*, *Monograptus flexilis* and *Cyrtograptus ellesae* Zones have been identified and documented in these sections by both index taxa and other characteristic species. Trilobites of the genera *Decoroproetus*, *Calymene* and *Diycalymene* also occur (Tomczykowa, 1957, 1990).

In the sections from the vicinity of Kielce, only the *Cyrtograptus rigidus-C. perneri* Zones are documented (Tomczyk, 1962*a, b*; Tomczykowa and Tomczyk, 1981). They correspond to the British uppermost Sheinwoodian comprising the *Cyrtograptus rigidus* to *C. ellesae* Zones. However, it is possible that the section is more complete because Czarnocki (In: Tomczyk, 1956) reported the zonal species *Cyrtograptus murchisoni* from the Mójcza area.

Upper Wenlock deposits are well represented in the Kielce region. A complete succession is known from around Kielce, Bardo and Międzygórz. The lowermost part of the sequence is preserved at Zbrza. Of the standard *Cyrtograptus lundgreni*, *Gothograptus nassa* and *Monograptus ludensis* Zones, (Harland *et al*., 1989), the former two are documented by index taxa (*cf.* Tomczyk, 1956, 1962*a*). The species *Monograptus ludensis* (Murchinson) has not been so far identified in the Kielce region (Tomczyk, 1990). The *Monograptus ludensis* Zone has been distinguished either from the occurrence of co-occurring graptolites (Tomczykowa and Tomczyk, 1981; Kowalczewski and Migaszewski, 1994) or, more often, replaced by the more or less coeval *Pristiograptus vulgaris* Zone (Tomczyk, 1956, 1962*a, b*, 1968).

The upper Wenlock deposits also contain trilobites representing genera such as *Odontopleura, Aulacopleura, Scharyia* and *Decoroproetus* (Tomczykowa, 1957, 1990).

Ludlow. The following standard graptolite zones have been established in the lower Ludlow (Harland *et al*., 1989): *Neodiversograptus nilssoni*, *Lobograptus scanicus* and *Saetograptus incipiens-Pristiograptus tumescens*. Lower Ludlow deposits of the Kielce region are well represented in the central area, particularly in the Prągowiec Gorge (Tomczyk, 1962*a*; Kowalczewski and Migaszewski, 1994), and in the west, near Kielce. They have been less studied in the eastern area. Rich graptolite assemblages found in the Ludlow deposits have allowed the recognition of from 4 to 7 graptolite zones (e.g. Tomczyk, 1962*a*) augmented with two subzones (e.g. Tomczykowa and Tomczyk, 1981). Four index taxa of standard zones have been found, of which two taxa — *Neodiversograptus nilssoni* (Lapworth) and *Lobograptus scanicus* Tullberg — have been employed in regional biostratigraphic schemes.

The stratigraphic position of greywackes from the Jurkowice exposure near Klimontów (Romanek and Rap, 1989) and Widełki exposure at Bardo (Stupnicka *et al*., 1991), containing no guide fossils yet assigned to the Ludlow, requires further study.

The international biostratigraphic scheme of the upper Ludlow includes the two biozones of *Saetograptus leintwardinensis* and *Bohemograptus* (Harland *et al*., 1989). These are represented in the Kielce region by the index taxa. Tomczyk (e.g. 1962*a, b*) in his older papers included the zones within the upper Ludlow, while in later ones (Tomczykowa and Tomczyk, 1981) only the *S. leintwardinensis* Zone was assigned to the uppermost Ludlow, whereas *Bohemograptus* became the lowermost zone of the new regional Siedlce series created by that author.

In the Widełki section near Bardo (Stupnicka *et al*., 1991) Porębska distinguished four graptolite zones above the *Saetograptus leintwardinensis* Zone, namely *Bohemograptus bohemicus*, *B. bohemicus-Neocucullograptus inexpectatus*, *N. inexpectatus* and *N. kozlowskii*. A yet more detailed subdivision of the *Bohemograptus* Zone into 6 graptolite zones was proposed by Tomczyk (1990).

Pridoli. Pridoli deposits are confidently documented only in the vicinity of Kielce (Malec, 1989, 1993, 1994; Kowalczewski and Migaszewski, 1994). No macrofauna has been found in the lower part of the sequence, whereas the upper portion contains a fairly varied fossil assemblage with brachiopods, ostracods, crinoids and, most notably, trilobites and graptolites. The following trilobites have been identified there: *Helokybe* cf. *spio* Thomas, *Balizoma* sp., *Dalmanites nexilis* (Salter), *Richterarges kielcensis* Tomczykowa and *Harpidella* sp. According to Tomczykowa (1993) this assemblage indicates the upper Ludlow. However, Teller (vide Malec, 1993) found *Pristiograptus transgrediens* (Perner) in the upper part of the sequence, indicating that at least part of the sequence belongs to the Pridoli.

The so-called Lipniczek Siltstones known from the exposures at Łączki and Lipniczek near Międzygórz are probably also of Pridoli age. These sections have yielded *Monograptus ultimus* (Perner) and the trilobite *Proetus conspersus* (Angel.) (Tomczykowa, 1959) which suggest that they may correspond to the Rzepin Beds (Tomczykowa, 1962).

RADOM AREA

In this region Silurian deposits were encountered in the Ciepielów IG 1 (Tomczyk, 1974, 1977; Tomczykowa, 1974, 1977) and Lisów 1 (Wierzchowska-Kicułowa, 1975) boreholes as well as in the nearly Warka IG 1 borehole. The Ciepielów IG 1 borehole was entirely cored while the remaining two boreholes were partially cored (Fig. 1). All the three Silurian sections are stratigraphically incomplete and do not range lower than the upper Ludlow (Ludfordian) (according to Tomczyk, 1974; Tomczyk and Tomczykowa, 1983) or presumably only down to the uppermost zones of this stage

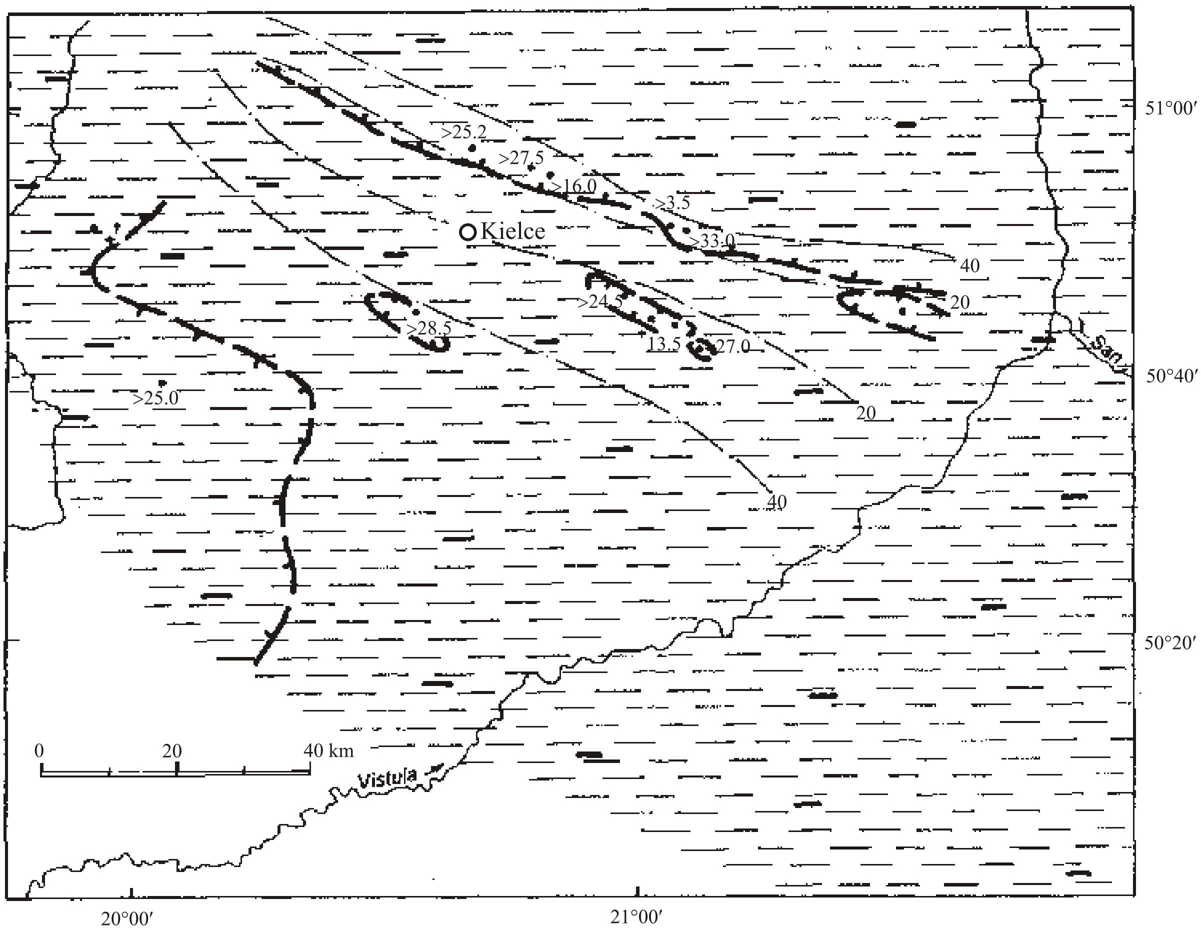

Fig. 6. Lithofacies-palaeothickness map of Llandovery deposits in the Nida and Holy Cross Mts. areas

(Ciepielów IG 1 borehole) (Teller, 1997). The Silurian deposits pass upwards with sedimentary continuity (Ciepielów IG and Lisów 1 boreholes) into Lower Devonian marine facies (Gedinnian), or they are unconformably overlain by Lower Carboniferous deposits (Żelichowski, 1972, 1979).

The most complete Silurian stratigraphic section is known from the Ciepielów IG 1 borehole. This section may be considered to represent this part of the Upper Silurian sequence of the Radom area.

Stratal dips in the Silurian sequence are variable and range from 6–8° to 70–80°. The apparent thickness of these deposits varies from 401.7 m in the Ciepielów IG 1 borehole to 651 m in the Lisów 1 borehole (Fig. 5).

LITHOLOGY

Sedimentary sequences of Silurian deposits in the Radom area have not so far been subdivided into regional formal or informal lithostratigraphic units. Their lithologies are briefly characterised below.

Upper Ludlow. Ludlow deposits were penetrated only by the Ciepielów IG 1 borehole. According to Tomczyk (1974) they occur there within the depth interval of 2885–3000 m (Fig. 5). The sequence spans the upper Ludlow (Ludfordian) and is conformably overlain by Pridoli deposits. The upper Ludlow sequence is represented by grey and grey-greenish compact siltstones which are commonly partially laminated, and sandy and argillaceous siltstones which are, locally variably calcareous. These rock types alternate at depth forming heterolithic intervals. They are strongly altered diagenetically and show variable degrees of fissility. The rocks commonly contain variable amounts of tuffaceous material, including pyroclastic quartz and biotite.

Pridoli. Pridoli deposits occur in all the three boreholes. However, they are confidently dated by fossils only in the Ciepielów IG 1 borehole (depth 2598.3–2885.0 m) where they are faulted but presumably represent, an originally complete stratigraphic sequence of the uppermost Silurian (Tomczyk, 1974). Their occurrence in the Warka IG 1 (depth 2740–3145 m) and Lisów 1 (depth 2540–3191 m) boreholes is not supported by any palaeontological data, and therefore the stratigraphic position of these deposits were interpreted variously. Doubts refer mostly to the clastic unit encountered in the Lisów 1 borehole below 2540 m. According to Teller (1997) this unit, tentatively assigned to the Pridoli, differs in its lithology, being represented by fine-grained glauconitic sandstones (Wierzchowska-Kicułowa, 1975, p. 266), from other uppermost Silurian sequences.

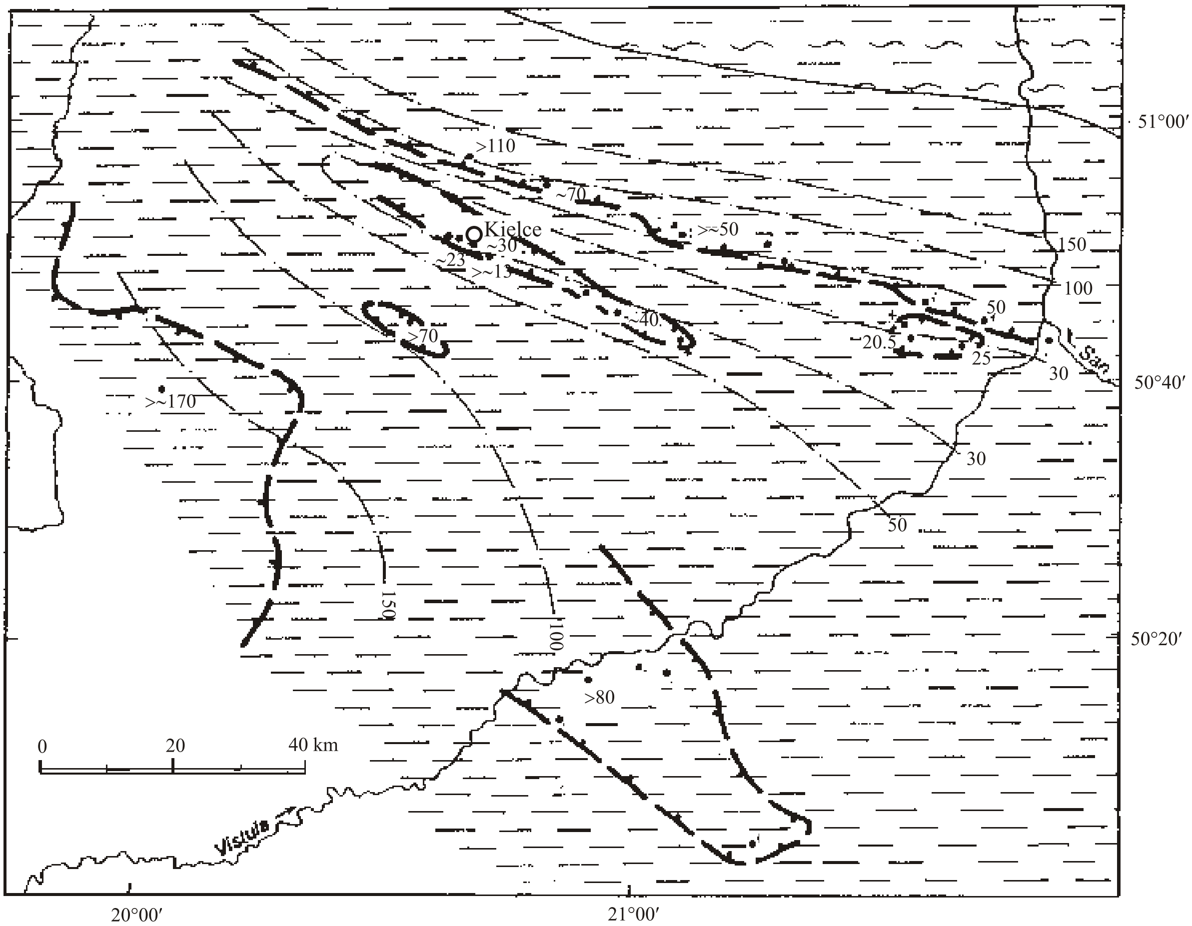

Fig. 7. Lithofacies-paleothickness map of Wenlock deposits in the Nida and Holy Cross Mts. areas

For explanations see Figure 9

The Pridoli is represented mostly by light grey and grey, locally greenish, compact claystones, siltstones and sandy siltstones. The rocks show more or less distinct lamination, locally they are calcareous or calcareous-dolomitic, fairly compact and hard, commonly highly fissile. Much of these succession contains occasional tuffaceous material, particularly in the silt-grade fraction.

Some of the siltstones and claystones from the Lisów 1 borehole show signs of strong secondary silification (Langier-Kuźniarowa, 1980). The claystone-siltstone succession from the Warka IG 1 borehole contains calcareous lenses and concretions.

The apparent thickness of the Pridoli deposits in the Ciepielów IG 1 borehole amounts to 286.7 m, whereas their minimum thicknesses in the two remaining boreholes are 405 m (Warka IG 1) and 651 m (Lisów 1) (Fig. 5).

BIOSTRATIGRAPHY

The Ciepielów IG 1 borehole provided most of stratigraphic and faunal data on the Silurian sequence and its relationships to younger deposits. The presence of Silurian deposits in the Warka IG 1 and Lisów 1 boreholes, as well as their presumed stratigraphic division, have been inferred from indirect evidence. It has been assumed that Ludlow or Ludlow-lowermost Pridoli deposits are likely represented in the Warka IG 1 borehole, whereas in the Lisów 1 borehole the Silurian sequence embraces the Pridoli or Pridoli-uppermost upper Ludlow (Fig. 5).

Upper Ludlow. Upper Ludlow deposits (= Lower Rzepin Beds) were encountered in the Ciepielów IG 1 borehole at depths of 2885–3000 m (Tomczyk, 1974) (Fig. 5). The lower part of the sequence (depth 2938–3000 m) yielded a fairly varied assemblage of graptolites represented, among others, by *Monograptus* ex gr. *formosus* Boucek, *Monograptus formosus* Boucek, *Monoclimacis* sp., *Monoclimacis* cf. *ultimus* (Perner), *Pristiograptus dubius* (Suess) and *Linograptus posthumus* Reinh. Richter. The upper part of the sequence (depth 2885–2938 m) includes *Monograptus formosus* Boucek, *Monograptus* ex gr. *formosus* Boucek, *Monoclimacis ultimus* (Perner) and a number of new species of the genera *Monograptus* and *Pristiograptus*. The upper boundary of the Ludlow was delimited by Tomczyk (1974) at the uppermost occurrence of *Monograptus formosus* Boucek, at a depth of

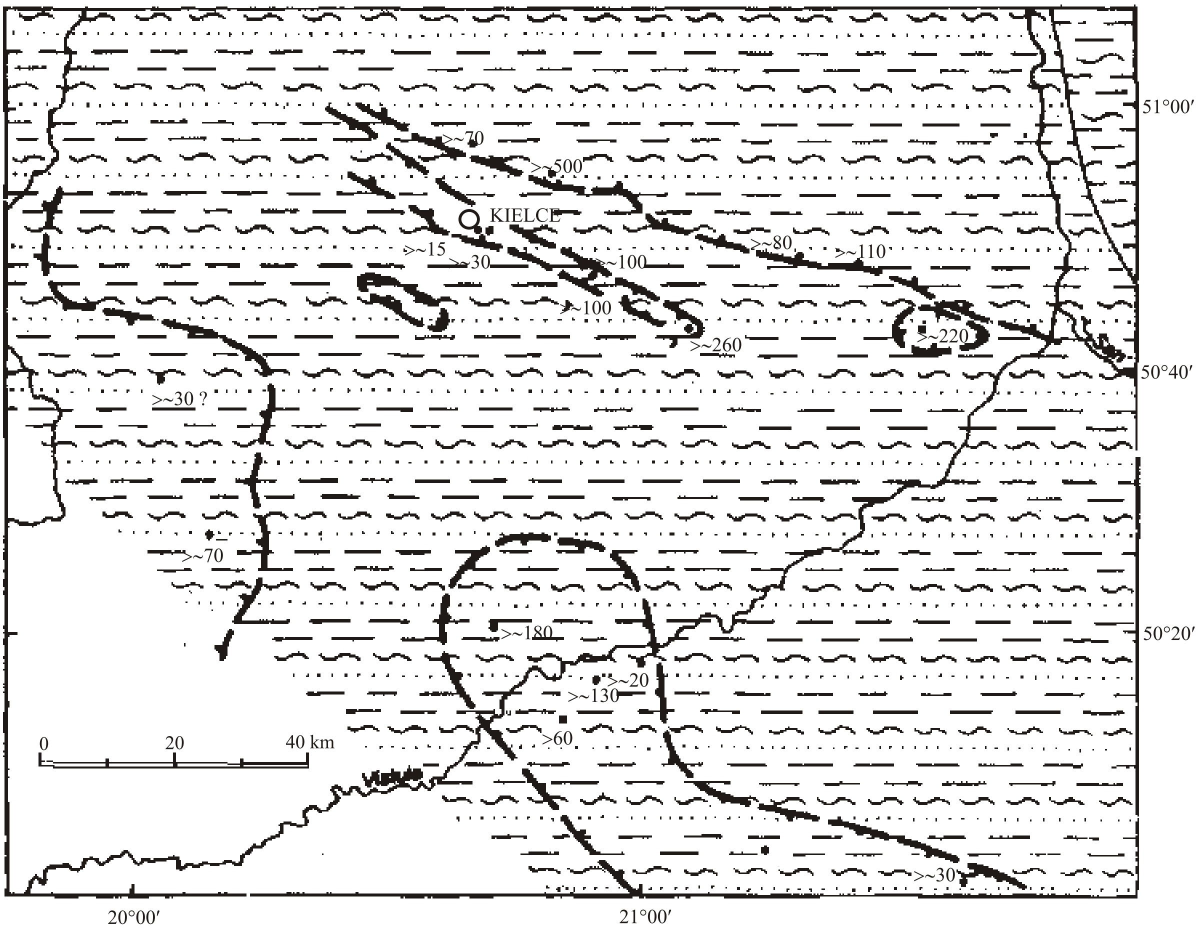

Fig. 8. Lithofacies-paleothickness map of Ludlow deposits in the Nida and Holy Cross Mts. areas

For explanations see Figure 9

2885 m. According to Tomczyk, the Silurian sequence drilled in the Ciepielów IG 1 borehole at depths of 2885–3000 m is represented by the upper Ludlow and may be correlated with deposits of the two informal regional stratigraphic units established by that author, namely the "Lower Rzepin Beds" of the Holy Cross Mts. area and the uppermost part of the "Upper Siedlce Beds" of the East European Platform.

Teller (1997) considered that stratigraphic interpretation of the Ludlow section in the Ciepielów IG 1 borehole proposed by Tomczyk (1974) may be questioned. Firstly, the graptolite assemblage cited by Tomczyk (1974) from depths of 2885.0–2912.2 m (27.2 m) does not indicate a precise stratigraphic position, seemingly corresponding only to the uppermost Ludlow, and not to the whole of the upper Ludlow as assumed by Tomczyk; secondly, the identification of *Monoclimacis* cf. *ultimus* (Perner) was incorrect because this species cannot co-occur with *M. formosus*, being an evolutionary successor of *M. paraultimus*, and so typical of a slightly younger level in the lower Pridoli; thirdly, misidentifications of graptolites makes the interpretation that the depth interval of 2912.2–3000.0 m (87.8 m) represents the lower Ludlow (Tomczyk, 1974) difficult to accept.

Pridoli. Pridoli deposits were penetrated by the boreholes Ciepielów IG 1 (depth 2598.3–2885.0 m), Warka IG 1 (depth 2740.0–3145.0 m) and Lisów 1 (depth 2540.0–3191.0 m). They are confidently documented by fossils only in the first borehole.

According to Tomczyk, Pridoli (= "Podlasie") deposits from the Ciepielów IG 1 borehole occur in sedimentary continuity with both the underlying upper Ludlow strata and the overlying Lower Devonian marine deposits (Gedinnian). Stratigraphically important graptolites were identified at depths of 2795.4–2885.0 m, 2767.0–2768.6 m, 2648.0–2675.0 m and 2605.0–2615.0 m. The lowermost deposits of this sequence have yielded *Monoclimacis ultimus* (Perner), *Pristiograptus* sp. and *Linograptus posthumus* Reinh. Richter. The rocks from depths of 2767.0–2768.6 m contain abundant *Monograptus* sp. and *Monoclimacis* cf. *ultimus* (Perner), indicating the lower Přidoli. The overlying deposits from depths of 2648.0–2675.0 m contain common graptolite fragments with dominant *Monograptus* cf. *angustidens* Pribyl and rare *Monograptus* sp. and *Linograptus*

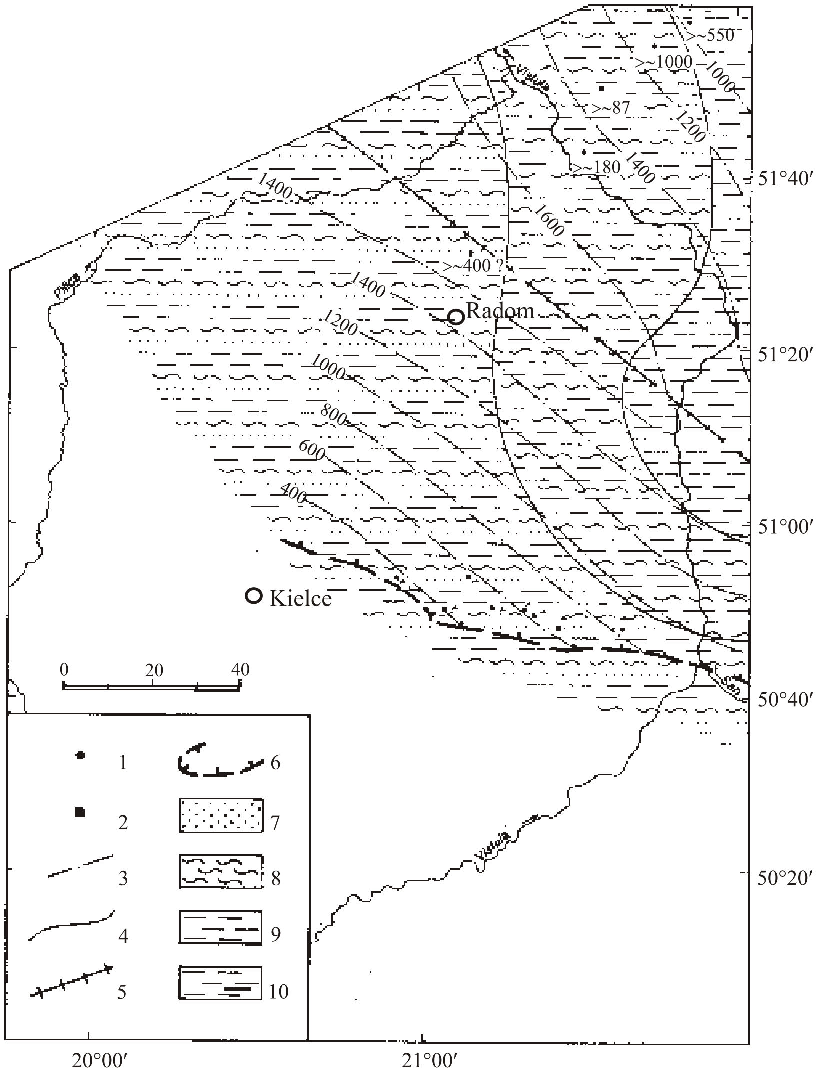

Fig. 9. Lithofacies-palaeothickness map of Pridoli deposits in the Nida, Holy Cross Mts. and Radom areas

1 — boreholes reaching the unit analysed with thickness given in metres; 2 — exposures of the unit analysed with thickness given in metres; 3 — palaeoisopachs of the unit analysed; 4 — lithofacies boundaries; 5 — hypothetical routes of faults within the Teisseyre-Tornquist Zone (T-T); 6 — recent extent of deposits; 7 — sandstones; 8 — siltstones; 9 — claystones; 10 — bituminous claystones

sp. The uppermost part of the succession has yielded specimens typical of the *Monograptus angustidens* Zone, including the index taxon *Monograptus angustidens* Pribyl.

According to Tomczyk (1974), the Pridoli succession from the Ciepielów IG 1 borehole has been affected by faulting, as evidenced by slickensides and stratal dip variation (50–80°). These are concentrated around depths of 2689.5–2721.8 m (32.3 m), 2721.8–2767.0 m (45.2 m) and 2768.6–2778.0 m (10.6 m). Missing intervals, span mid-Pridoli time above the *Monoclimacis ultimus* Zones, and encompass the *Pristiograptus chełmiensis* Zone up to the *Pristiograptus transgrediens* Zone, inclusive. Pridoli deposits of the Ciepielów IG 1 borehole are stratigraphic and lithologic equivalents of the so-called Podlasie Beds of the East European Platform, and, on a regional scale, they may be considered equivalents of the so-called Upper Rzepin Beds of the Łysogóry area.

Teller (1997) considered that the stratigraphical interpretation of the Pridoli section in the Ciepielów IG 1 borehole proposed by Tomczyk (1974) needs amendment. For the graptolite assemblage, cited by Tomczyk (1974) from depths of 2605.0– 2689.5 m as dating the “Podlasie = Upper Rzepin Beds”, contains in fact fossils typical of the lower Gedinnian, not Upper Silurian because internationally the Silurian/Devonian boundary is now placed at the base of the *M. angustidens* Zone; the Silurian/Devonian boundary in the Ciepielów IG 1 borehole should thus be moved down to a depth of 2689 m. This boundary is marked in wireline logs by a distinct change of the gamma ray curve. The shift of the Silurian/Devonian boundary must also result in redefinition and correction of the Gedinnian/Siegenian boundary. According to Teller, graptolites from depths of 2767.0–2885.0 m, faulting recorded at depths of 2767.0 m, 2795.4 m, 2852.0 m and 2885.0 m, and incorrectly identified of graptolites, particularly of specimens determined as *Monograptus ultimus*, indicates that the stratigraphical interpretation proposed by Tomczyk (1974) needs revision.

LITHOFACIES

Interpretations of the Silurian facies pattern in the Holy Cross Mts. and its environs were given by Tomczyk (1960), Tomczyk and Jaworowski (1974) and Kowalczewski (1994). Lithofacies-palaeothickness sketch-maps of Llandovery, Wenlock, Ludlow and Pridoli deposits given in this paper illustrate the spatial variability of the two principal elements — the lithologies of individual series and their original thicknesses. Lithologic variability is expressed by the record of all sedimentary processes that operated during each epoch. Original thickness variability is a total of all vertical movements of the basement, which influenced sedimentation and erosion. Superposition of the sketch-maps produced enables a reconstruction of the major events in the Silurian sedimentary basin development of this region.

Variability in our knowledge of the Silurian deposits and in the degree of geological exploration between particular regions means that the reliability of reconstruction varies from area to area.

The reconstructions of the Nida and Radom areas may be especially suspect. The sketch-maps here are generalised to illustrate the overall facies pattern, with estimated reconstructions of original thicknesses. The limited data means that the Silurian facies pattern is based simply on standard depositional models of shallow siliciclastic open-shelf and deeper intrashelf basinal systems.

The vertical lithofacies succession shows that they probably correspond to three consecutive phases of regressive evolution the basin as evidenced by a transition from dark claystones with lydites (Llandovery, Wenlock) through claystone-siltstone and siltstone-claystone facies (Ludlow) into siltstone-claystone deposits with a considerable interbedded sandstone (Pridoli).

Llandovery. Llandovery map (Fig. 6) shows that clays generally dominated, with little lateral variability in sedimentary processes and environmental conditions. These deposits largely comprise black, locally bituminous, laminated claystones with subordinate siltstones, fine-grained sandstones, limestones and lydites. The isopach pattern shows a narrow zone of minimum thicknesses which, in the central area, is defined by the 20 m isopach. This zone presumably corresponds to a minimum subsidence zone with uplift along a “central” palaeohigh (Kowalczewski *et al.*, 1986). The isopach pattern also shows that thicknesses gradually but consistently increase towards both the NE and SW away from this zone. There is a consistent WNW–ESE trend in the isopachs.

Wenlock. The Wenlock map (Fig. 7) shows that the only lithofacies recognised are claystones. The isopach pattern indicates that the Wenlock deposits are thinnest within a narrow zone defined by the 30 m isopach. This zone stretches across the Kielce segment of the Holy Cross Mts. area with thicknesses of the Wenlock deposits gradually increasing towards both the NE and SW. The general trend of isopachs resembles that observed for Llandovery deposits (Fig. 6) and more or less parallel the Teisseyre-Tornquist Line, i.e.

Ludlow. The Ludlow map (Fig. 8) shows two lithofacies areas represented by claystone-siltstone-sandstone and claystone-siltstone deposits respectively. The extent of the former encompasses the Nida Trough area, the Holy Cross Mts. region and most of the Radom area. The latter embraces the northwestern peripheries of the Radom area. The reconstructed maximum values of Ludlow thicknesses range from 800 m to approximately 1200 m. The general trend of isopachs does not change considerably, from that of the Wenlock approaching the T-T Line at an acute angle

Pridoli. The Pridoli map shows three lithofacies areas. These are (from the SW) of: claystone-siltstone-sandstone, claystone-siltstone and clay (Fig. 9). The first of these occupies the Łysogóry segment of the Holy Cross Mts. and the western part of the Radom area. The second stretches across the mid-western part of the Radom region. The third area covers the easternmost part of the Radom region around the Ciepielów IG 1 borehole. The estimated limits of these areas of the map show a general N–S trend with a change to SSE–NNW in the north and south. The isopach pattern indicates that Pridoli deposits are thickest in the central area of the Radom region. The axis of maximum thickness extends along a line between the Ciepielów IG 1-Lisów 1 boreholes, and thicknesses gradually decrease towards both the NE and SW of this axis. The general trend of isopachs is NW–SE.

SUMMARY

1. The state of geological exploration of Silurian deposits is incomplete and varies between individual areas. Silurian deposits of the Holy Cross Mts. are known from both the Łysogóry and Kielce regions, and have been described from about 26 natural exposures and 37 boreholes. They were also encountered in four boreholes drilled in the Nida area, and three boreholes drilled in the Radom region (Fig. 1).

2. The Silurian complex of the Holy Cross Mts. area is underlain, either with sedimentary discontinuity (Mokradle 1, Wilków 1 boreholes and Zbrza) or across tectonic contacts (Kędziorka 1, Jeleniów 1 boreholes and Pobroszyn), by rocks of different ages. In the Nida area Silurian deposits unconformably rest upon Ordovician rocks (Fig. 2), and are more or less erosionally truncated and overlain by Lower Devonian or Lower Triassic sequences.

3. Silurian deposits of the Radom region have not been completely penetrated by any borehole (Fig. 5). Knowledge of the Silurian succession has been derived mostly from the Ciepielów IG 1 borehole, probably spanning the Upper Ludlow and Pridoli. The occurrence of Silurian deposits in the Lisów 1 borehole is indicated by indirect evidence. The Silurian deposits grade upwards with sedimentary continuity into Gedinnian marine facies.

4. Silurian deposits of the Łysogóry region are conspicuous by a complete development of marine facies with no significant sedimentary gaps or non-depositional intervals, and a continuous transition into Lower Devonian marine facies. The Silurian sequence of the Kielce region shows numerous sedimentary gaps, spanning variable time intervals, interpreted as signs of the synorogenic Taconic movements lower in the sequence, and Ardenian movements in its upper part. Silurian deposits of the Kielce region most likely underwent denudation after the Erian movements, and were later unconformably overlain by Siegenian or Emsian deposits.

5. Revision of the boundaries of individual series in the Upper Silurian is necessary, to apply the international standard division and to enable precise inter-regional correlations. This requires, re-examination of graptolites as regards their identity and ranges.

6. Lithologic variability in a vertical succession of Silurian deposits in the Nida, Holy Cross Mts. and Radom areas has enabled lithostratigraphic subdivision. The schemes proposed by different authors are mostly informal and frequently take non-lithological features into account. Future lithological investigations should be focussed on the following and tasks:

— subdivision of the Silurian sequence in the Nida and Radom areas;

— studies of regional lithologic and thickness variations within the units established in the Kielce and Łysogóry regions, together with determination of their boundaries;

— definition of standard litho- and hypolithostratotypes of individual units in the Kielce and Łysogóry regions,

— establishing and defining of lower rank lithostratigraphic units (i.e. members and beds) within individual formations;

— verification, codification and formalisation of these and earlier created units.

7. Silurian deposits show lateral lithologic and thickness variations. The vertical succession of lithofacies units may be interpreted in terms of three consecutive phases of the overall regressive evolution of the basin. The succession shows a gradation from dark clay deposits with lydites (Llandovery, Wenlock) through claystone-siltstone and siltstone-claystone facies (Ludlow) into siltstone-claystone deposits with a considerable sandstone content (Pridoli).

Acknowledgements. The authors express cordial thanks to Professor Ryszard Dadlez, Dr. Zbigniew Kowalczewski and Dr. Marek Narkiewicz for their remarks and cooperation in preparation of the final version of the paper.

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