Geological Quarterly, 1998, 42 (4): 421–442

Petrology and lithofacies of the Tremadoc epicontinental-marine siliciclastic sequence in the Lublin area (SE Poland)

Bronisław SZYMAŃSKI

Szymański B. (1998) — Petrology and lithofacies of the Tremadoc epicontinental-marine siliciclastic sequence in the Lublin area (SE Poland). Geol. Quart., 42 (4):421–442. Warszawa.

Results of lithological, petrographical and chemical analyses of the transgressive-regressive sediments of Tremadoc series are presented based on 17 borehole sections from the Lublin area. The studied sequence predominantly comprises siliciclastic rocks of various grain sizes. Nonterrigenous rocks are of minor importance. These include carbonates (limestones, dolomitic limestones) and siliceous rocks (chalcedonites). A dominant part of the terrigenous sequence is composed of medium- and fine-grained sandstones of dense grain framework and textural features characteristic for quartz arenites. Sandstones belonging to "wacke" group occur less frequently mainly in sections from the southern part of the region. Intensive pre-Arenig erosion is accepted as a dominant reason for incomplete stratigraphic record of the Tremadoc in the investigated sections.

Bronisław Szymański, Polish Geological Institute, Rakowiecka 4, 00-975 Warszawa, Poland *(received: 8.10.1998; accepted: 4.12.1998).*

Key words: Tremadoc, petrology, clastic rocks, carbonates, chalcedonites, SE Poland (Lublin region).

INTRODUCTION

Sediments of the Tremadoc age were drilled in the Lublin region initially in the borehole Krowie Bagno IG 1 (depth 2762.5–2765.0 m), which was made in years 1968–1970 in the Chełm Lubelski area by the Polish Geological Institute. In the following years occurrence of these sediments was determined in other 16 boreholes located in various structural positions (Fig. 1). Six of these boreholes were made by the Polish Geological Institute, while remaining ten — by the Polish Oil and Gas Company.

Until the end of the 1970s described sediments, despite a distinctive contrast with underlying Cambrian sediments, transgressive position and stratigraphic unconformity at the bottom of the sequence, were assigned to various stratigraphic horizons (K. Lendzion *et al.*, 1979): initially Middle Cambrian (K. Lendzion, 1971, 1975*a*), then with a question mark or partly Upper Cambrian or Tremadoc (K. Lendzion, 1975*b*), or in part Middle Cambrian or Upper Cambrian (K. Lendzion,1976), finally Tremadoc (Z. Modliński, 1975, 1984*a*, *b*). Palaeontologic data including index taxa of inarticulate brachiopods *Obolus* (boreholes: Parczew IG 10, Busówno IG 1, Bachus 1 Łopiennik IG 1), poorly preserved fragments of graptolite rhabdosomes (Łopiennik IG 1) and rich assemblage of acritarchs (Łopiennik IG 1, Wierzbica 1 — oral inf. M. Moczydłowska), finally enabled the decision as to its Tremadoc age.

Cores and drill cuttings of Tremadoc rocks from 17 boreholes, drilled in the described area for various purposes in years 1968–1992, were used as the source of analytical material. Six among these boreholes were fully cored within the Tremadoc interval, nine had partial coring, and remaining two were sampled without coring (Kock 5, Tarkawica 3). Identification and determination of lithological characteristics of Tremadoc in uncored borehole sections were based on analysis of drill cuttings and interpretation of geophysical logging — mainly measurement records of PG and PNG.

Investigated Tremadoc sequence developed transgressively upon the sandstones of *Paradoxides paradoxissimus* (Łopiennik IG 1) or *Eccaparadoxides oelandicus* Zones of the Middle Cambrian (K. Lendzion, 1983*a*, *b*), and is overlain by conglomeratic-glauconitic sediments of the lower Arenig (Latorp B_I). The Tremadoc series contacts with sediments of

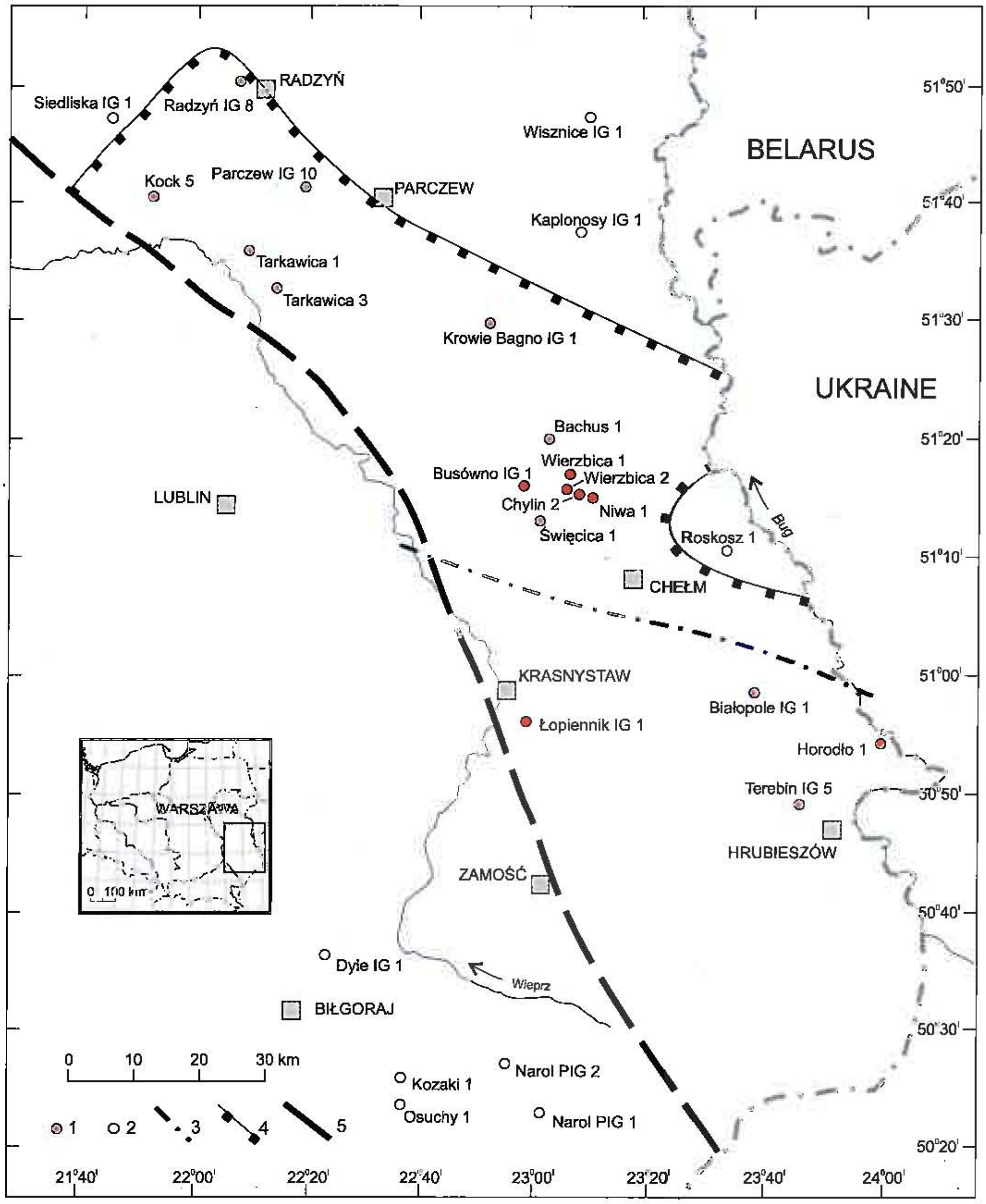

Fig. 1. Location of studied boreholes in the Lublin region

1 — boreholes where Tremadoc sediments were described; 2 — other boreholes which reached the Lower Palaeozoic; 3 — lithofacies zone boundary; 4 — erosional boundary of a suspected extent of Tremadoc sediments; 5 — Teisseyre-Tornquist (T-T) line (partly according to J. Znosko, 1998)

Mapa lokalizacji otworów wiertniczych na obszarze Lubelszczyzny

1 — otwory wiertnicze, w których opracowano osady tremadoku; 2 — inne otwory wiertnicze osiągające osady starszego paleozoiku; 3 — granica stref litofacjalnych; 4 — erozyjna granica przypuszczalnego zasięgu osadów tremadoku; 5 — granica strefy Teisseyre'a–Tornquista (częściowo według J. Znoski, 1998)

the Cambrian and Arenig respectively along distinct regional erosional surfaces (Fig. 2). Stratigraphic record of the series comprises: lower Tremadoc (Pakerort A_{II}) and palaeontologically undocumented upper Tremadoc (Ceratopyge A_{III}), whose occurrence is locally accepted in borehole section Łopiennik IG 1 (K. Lendzion *et al.*, 1979).

Total measured interval of investigated Tremadoc sediments is about 288.0 m with 196.0 m of core available. Petrographical study was based on 150 standard thin sections, 24 polished surfaces. Additionally, 40 complete (14 components) and 30 simplified (5 components) chemical and spectral analyses were conducted. Part of the thin sections were stained with alizarine-S and Evamy's solution in order to identify carbonate minerals (G. M. Friedman, 1959, 1971; Z. Migaszewski, M. Narkiewicz, 1983).

Conducted research included detailed lithologic description, sedimentological observations, qualitative and quantitative petrographic and microfacies analyses of thin sections and quantitative chemical and spectral analyses. Lithology of uncored intervals was identified basing on cuttings and interpretation of geophysical logging records, mainly measurements records of PG and PNG, callibrated with observations of cored intervals. In the microscopic analysis the following qualitative and quantitative parameters were used: mineral composition as % vol., bioclastic material content and character, structures and textures, size of a largest (d_{max}) and a most frequent (d_f) quartz grain, finally roundness and sphericity of grains and their contacts. Their determination was conducted by means of point geometrical analysis by using from 250 to 500 measurement points of specific parameters on integral table ELTINOR 4, in every thin section. Grain size scale was adopted after F. J. Pettijohn *et al.* (1972), whereas roundness was approximately determined by comparison with graphical standards (R. L. Folk, 1968).

General types of clastic and carbonate rocks were determined based on mineral composition, textural features and content and character of allochemical components. For intensely recrystallized carbonate rocks, however, a simplified classification was used, including the following types of rocks: sparite, clayey sparite, and sparse biosparite. Terminology of R. L. Folk (1959, 1968) was used as the basis of carbonate classification, and terminology of R. L. Dott with modifications of F. J. Pettijohn *et al.* (1972) was used for clastic rocks. An upper grain size limit of 0.063 mm was assumed for the matrix, i.e. value of 4 in the phi scale. According to this assumption, matrix in the described sandstones is mainly categorized as clayey cement. Classification of sedimentological structures was adopted according to the textbook by R. Gradziński *et al.* (1986).

Thin and polished sections were prepared in Petrology Department of the PGI, spectral and chemical analyses in the Central Chemical Laboratory (PGI), thin-section photographs were taken by J. Modrzejewska, figures were drawn by T. Grudzień. Documentation of lithologic samples, thin sections and results of chemical analyses is stored in the Department of Regional and Petroleum Geology, PGI, Warsaw.

LITHOLOGICAL-PETROGRAPHIC DESCRIPTION

Lithological record of the Tremadoc is represented by transgressive-regressive sequence, which includes clastic, carbonate and siliceous (chalcedonites) sediments. Thickness of this sequence is variable and ranges from 0.2–2.0 m (Parczew IG 10, Radzyń IG 8) to 11.0–43.0 m (Wierzbica 1, Łopiennik IG 1).[1]

CLASTIC ROCKS

Clastic rocks are composed of polimictic conglomerates, oligomictic, variably-, medium- and fine-grained sandstones as well as siltstones and claystones. Their vertical succession and mutual thickness proportions in particular sections are variable: siltstones and claystones prevail in sections of the southern area, while sandstones, mainly of quartzitic arenite textural characteristics in the northern area (Fig. 2).

Chemical composition of major types of clastic rocks of the Tremadoc are presented in Tab..1.

CONGLOMERATES

In the studied sections conglomerates represent subordinate lithology displaying poorly differentiated development (Fig. 2). Rocks containing at least 10% of grains representing lithoclasts with diameter greater than 2.0 mm (i.e. less than 1 phi) are assigned to this lithological type. Their occurrence was determined at the base of the sequence (i.e. Parczew IG 10, Łopiennik IG 1, Wierzbica 1), where they form locally developed transgressive horizon of polimictic basal conglomerates, and in the vicinity of some intraformational erosional surfaces (Łopiennik IG 1, Busówno IG 1). The measured thickness of the basal layer of conglomeratic rocks is insignificant and ranges from 0.2 to 3.0 m.[2]

Conglomerates are cohesive, hard rocks with irregular fractures and are strongly altered diagenetically. Their colour is uniform: gray or dark gray, occasionally with brownish hue (Bachus 1). Commonly, these rocks macroscopically lack a distinctive layering and display a poor selectiveness and a low degree of sorting. Significant rock parts are intensely either silicified, cemented with carbonates or impregnated by phosphates. Occurrence of sedimentological structures has not been determined in the conglomerate, however, joints and small veins filled with carbonates or quartz, occasionally with pyrite, are often observed. Conglomerate structure is varigrained, psephito-psammitic, texture — unoriented, concretionary in parts.

Qualitative conglomerate lithologic-mineral composition is weakly diversified and does not display any significant lateral variation. Conglomerates are composed of three basic textural components of different origin: coarse-clastic detrital material, mixed cement — detrital type of matrix, actual cement, and authigenic minerals.

Coarse grain fraction mainly comprises exoclasts of Cambrian sedimentary rocks of local provenance. They are rather uniform in composition representing fine- and medium-grained quartz sandstones with quartz overgrowths cement and light gray or gray colour, vein quartz, dark gray and gray phosphate and phosphate-clayey rocks, and dark gray silt-

[1] These are incomplete thicknesses, whose variability in particular sections results from combination of mainly three factors, i.e. palaeotopography of the basal unconformity, spatial variability of subsidence rate and a variable degree of pre-Arenig erosion.

[2] Insignificant thickness of basal conglomerates, their local occurrence and commonly marked condensation of basal members of transgressive Tremadoc sediments in the analyzed sections is a regional phenomenon. It was caused in a significant degree by peneplenization of pre-Tremadoc land areas, lithologic character of occurring rock complexes and by significant rate of the Tremadoc marine transgression.

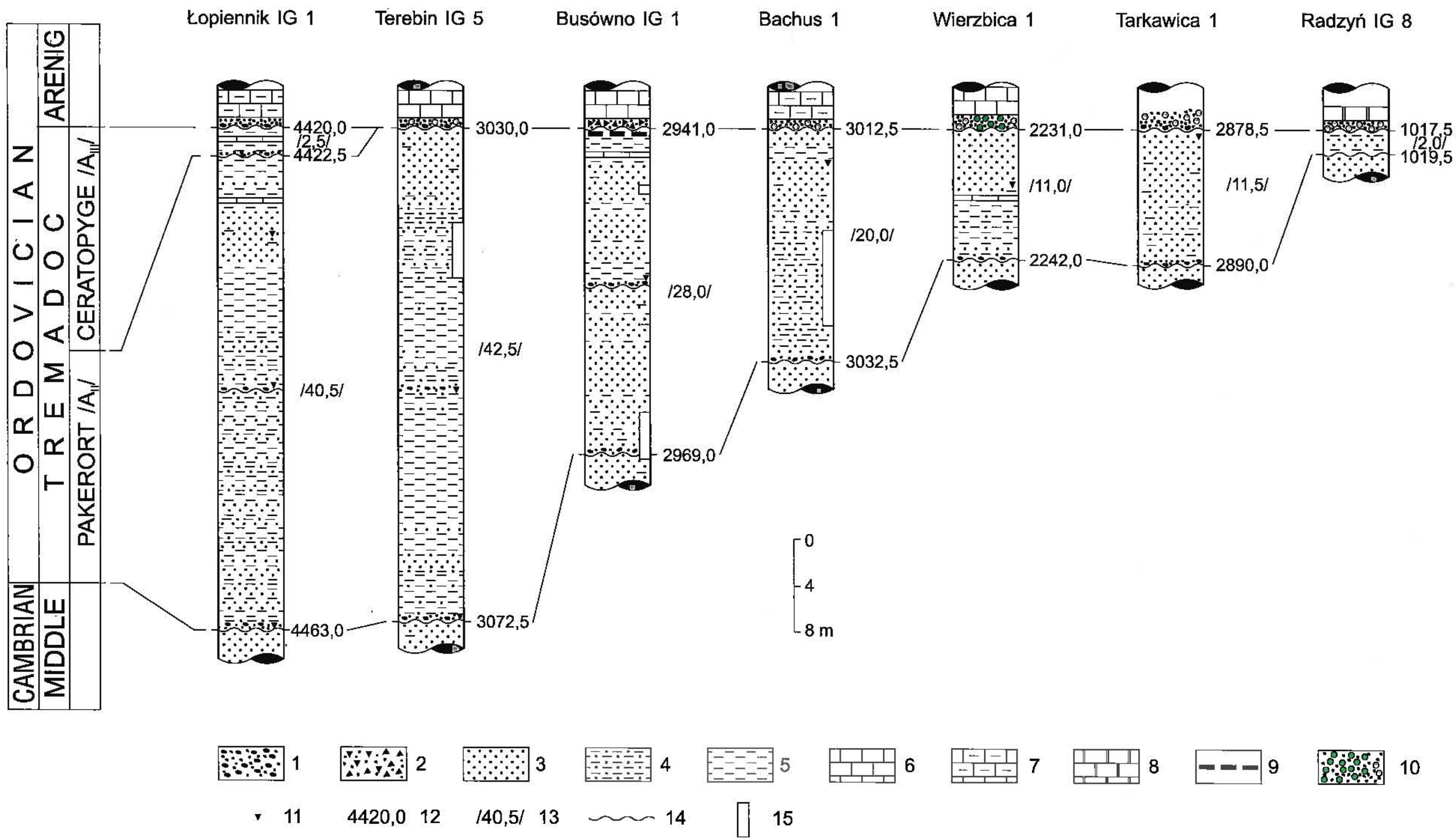

Fig. 2. Correlation of Tremadoc sections in the Lublin region

1 — conglomerates and vari-grained sandstones; 2 — tectonic breccias; 3 — medium- and fine-grained sandstones; 4 — siltstones; 5 — claystones; 6 — limestones; 7 — marly limestones; 8 — dolomites; 9 — siliceous rocks (chalcedonites); 10 — glauconite; 11 — pyrite; 12 — depth in meters; 13 — series thickness in meters; 14 — erosional unconformity; 15 — uncored intervals

Zestawienie korelacyjne profilów litologicznych tremadoku Lubelszczyzny

1 — zlepieńce i piaskowce różnoziarniste; 2 — brekcje tektoniczne; 3 — piaskowce średnio- i drobnoziarniste; 4 — mułowce; 5 — iłowce; 6 — wapienie; 7 — wapienie margliste; 8 — dolomity; 9 — skały krzemionkowe (chalcedonity); 10 — glaukonityty; 11 — piryt; 12 — głębokość w metrach; 13 — miąższość serii w metrach; 14 — niezgodności erozyjne; 15 — odcinki nierdzeniowane

stones and claystones of laminated or homogeneous texture. Commonly, sandstones (Łopiennik IG 1, Bachus 1), and more rarely siltstones and claystones (Terebin IG 5) are dominant in the lithologic composition of coarse-clastic material. Grains of the lithic material are distributed chaotically and irregularly, and the most often they do not contact with other lithic grains, or exceptionally they contact only in individual points. Lithic material content is variable and ranges from 20 to 60% of the rock volume. Shapes of most of the clasts are oval or isometric, less frequently prismatic or elongated — platy in the case of claystones. Commonly, semi-rounded and rounded clasts with polished surfaces dominate. Maximum diameter of coarse-clastic components does not exceed 4 cm, and a diameter of a dominant fraction is between 1.4 and 2.0 cm (Łopiennik IG 1, Parczew IG 10).

The matrix is mainly composed of detrital quartz of sand and silt fractions, clay minerals from illite-chlorite group, occasionally with kaolinite admixture, scarce kaolinitized feldspar grains (plagioclase, microcline), individual grains of light green aggregated glauconite, altered to a various degree, and small flakes of muscovite, exceptionally of biotite. Grained biogenic material, which forms small clasts and fragments of phosphate-chitinous shells of inarticulate brachiopods, often calcitized to a various degree (Łopiennik IG 1, Parczew IG 10, Bachus 1), or pyritized (Terebin IG 5), is a quantitatively subordinate component in many samples. Among authigenic minerals, there have been observed variable amounts of carbonates (predominantly calcite and/or dolomite, occasionally siderite and/or ankerite?), quartz, recrystallized cryptocrystalline silica, brown and colourless isotropic phosphates, iron hydroxides and oxides, and sulphides — mainly pyrite. Mineral composition of conglomerates is complemented by a poor assemblage of heavy minerals — zircon, anatase, tourmaline, epidote, leucoxene, magnetite, titanite, apatite, more rarely rutile.

Conglomerate cement is commonly abundant and not uniformly distributed, of the passive or matrix type, in parts of concretionary character (phosphates, silica). Matrix type of a cement is composed of sandy-clayey or silty-clayey, exceptionally clayey material. Proper (passive) cement type is formed of carbonates — mainly calcite and/or dolomite, phosphates, authigenic quartz, iron hydroxides and oxides and pyrite.

Basal conglomerates are laterally replaced by vari- and medium-grained quartz sandstones, containing individual, small exoclasts of local provenance. These rocks form a transgressive part of the Tremadoc sequence, whose origin is probably associated with marine near-shore environments of rapidly transgressing epicontinental marine basin. Consequently, these deposits are interpreted as heterogeneous sediments, reflecting the earliest stages of the transgression occurring diachronously in different sections. Their detrital material originated from disintegration of older, mainly Cambrian, sedimentary rocks and was deposited as a result of rapid, short-term depositional events.

SANDSTONES

Sandstones are represented by texturally heterogeneous rock group occurring in all studied sections. They comprise from about 30 (Łopiennik IG 1) to 90% of the total thickness of the investigated sequence (Parczew IG 10).

Petrographic composition of the sandstones is presented in Fig. 3. These are massive, cohesive and hard or very hard rocks with a variable — mostly significant — degree of diagenetic alterations. Their colour is non-uniform: gray or light gray (Łopiennik IG 1, Bachus 1), or in parts secondarily enriched in iron hydroxides and oxides or bituminous material — gray-brown (Parczew IG 1, Wierzbica 1). A significant part of sandstones is fractured and cross-cut by irregular veins and microveins of carbonates or quartz, occasionally chlorite. Present are, particularly in sequences of the southern region, uneven surfaces of intraformational erosion, poorly preserved stylolites of various origin and poor spectrum of sedimentary structures including bioturbation, current hieroglyphs and synsedimentary deformation structures.

The sandstones are mainly fine- and medium-grained, subordinately vari-grained (Pl. I, Figs. 4, 6, 7; Pl. II, Figs. 8, 9), occasionally with silt admixture (Pl. I, Fig. 5). The texture is homogeneous (Pl. I, Figs. 4, 6, 7; Pl. II, Figs. 8, 9) or exceptionally concretionary in parts. Sporadically, mainly in basal part of the southern region sequence, wavy or horizontal lamination occurs and is emphasized by parallel or weakly diagonal lamination of clayey material.

Sandstones in the studied sections form commonly indistinct units representing either simple layers of uniform lithology or complex beds, consisting of layers of uniform or gradational lithology. Their thickness is variable and for both described types ranges from 0.2 to 0.5 m, and from 0.6 to 2.0 m, respectively. Former units are commonly weakly contrasting and with macroscopically indistinct boundaries, while units of complex layers are isolated and well-defined, and/or form intercalations with siltstones and claystones. Their contacts with these litologies are commonly gradual and smooth, so that it may be macroscopically difficult to pinpoint boundaries of specific lithologic types. Occasionally top surfaces of these layers are distinct and clear, slightly uneven and have features characteristic for unconformity surfaces of subaqueous origin. Simple layer complexes dominate in sections of the northern part of the area, while units of complex layers in the southern part.

Sandstones are characterized by monotonous and poorly differentiated mineral composition. The investigated sandstone samples belong in considerable majority to quartz arenites, subordinately — mainly in sequences of the southern region — are represented by quartz wackes, and but exceptionally in a basal part they are composed of sublithic wackes (Terebin IG 5, Łopiennik IG 1). The essential part of quartz arenites comprises rocks with either carbonate cement (Pl. I, Figs. 6, 7; Pl. II, Fig. 8), or overgrowths quartz cement (Pl. I, Fig. 4; Pl. II, Fig. 9, exceptionally quartz-phosphatic (Pl. I, Fig. 4).

Table 1

Chemical composition of sandstones (a), mudstones (b) and claystones (c) in the Tremadoc of the Lublin region (weight %)

Well	Depth [m]	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	P_2O_5	Sc	CO_2	Total
Krowie Bagno IG 1	2763.5(a)	70.92	1.22	12.57	2.76	1.07	0.00	1.90	1.04	0.27	4.43	0.06	0.60	1.27	98.11
Wierzbica 1	2232.0(a)	66.88	0.85	11.30	4.54	1.65	0.09	2.03	0.88	0.25	4.32	0.13	2.32	3.33	98.57
Wierzbica 1	2233.5(a)	63.59	0.83	15.80	3.22	2.02	0.07	2.35	1.95	0.31	4.60	0.19	0.34	2.32	97.59
Wierzbica 1	2235.0(b)	57.17	0.96	19.09	4.68	2.34	1.10	0.78	2.21	0.30	5.24	0.14	3.06	1.85	98.92
Wierzbica 1	2235.5(b)	58.32	0.96	18.10	5.26	2.37	0.08	0.70	3.01	0.28	4.79	0.14	3.51	1.00	98.52
Niwa 1	1122.5(a)	72.30	0.65	12.50	0.77	0.35	0.20	1.65	1.62	0.40	4.20	0.33	0.60	3.40	98.97
Niwa 1	1123.5(a)	72.25	0.82	10.20	0.80	0.21	0.60	1.54	1.80	0.72	2.56	1.30	0.50	3.52	96.82
Bachus 1	3013.5(a)	61.06	0.65	4.29	11.16	7.90	0.09	3.68	3.07	0.35	1.49	1.49	0.20	3.80	99.23
Bachus 1	3016.5(a)	66.10	0.82	5.30	4.76	1.09	0.20	3.96	0.94	0.92	2.49	0.93	0.40	5.30	93.21
Bachus 1	3018.0(a)	64.20	0.80	5.20	2.36	0.30	0.16	5.66	1.18	0.70	2.80	0.90	0.60	7.40	92.26
Łopiennik IG 1	4421.5(c)	70.60	0.55	14.30	2.13	3.13	0.02	1.45	1.45	1.30	2.28	0.08	1.60	0.80	99.69
Łopiennik IG 1	4421.7(c)	72.11	0.00	15.11	1.50	3.02	0.01	1.58	1.09	3.37	0.42	0.04	0.09	0.50	98.84

Analyser by the PGI Central Laboratory.

Sandstones are composed of three textural components of a different origin, occurring in variable quantitative proportions: clastic material forming grain framework, cement of the matrix type and a proper cement or overgrowth cement and other diagenetic mineral phases.

Grain framework is made of quartz (65.0–90.0% vol.), individual small muscovite flakes (~1.0% vol.), exceptionally noted biotite and opaque grains and fragments of feldspars (<1.5%), among which plagioclase and microcline were distinguished. Among other components, small bioclastic grains are present occasionally (Pl. I, Figs. 6, 7), individual exoclasts of sedimentary rocks (Pl. II, Fig. 9) — mainly clayey and phosphatic (Pl. I, Fig. 6), jagged concentrations of an isotropic bituminous substance and aggregate grains of light green glauconite (~ 1.0%). Mineral composition of the rock is complemented by a poor assemblage of heavy minerals — zircon, anatase, tourmaline, leucoxene, magnetite, pyrite and apatite, rare rutile, pyroxenes (hypersthene?), epidote, titanite. Content of heavy minerals is insignificant and on average ranges from 0.3 to 1.5% vol., only exceptionally 2.0% vol. Usually, opaque minerals (pyrite, magnetite, leucoxene) predominate, while the transparent ones are represented mainly by well-rounded grains of zircon, tourmaline and rutile.

Grains are well-rounded and moderately- (wackes) or well-sorted (arenites). Commonly grains of the psammitic fraction are better rounded than those of aleuritic fraction. Their majority is of spherical or oval shape. The mean size of the most frequent quartz grain (d_f) in fine-grained sandstones ranges from 0.13 to 0.16 mm, which corresponds to values 2.95 and 2.5 in the phi scale, whereas in medium-grained sandstones it is 0.35 mm. The mean size of a maximum quartz grain (d_{max}) in fine-grained sandstones is 0.21 mm, and in medium-grained sandstones it reaches 0.84 mm. Occasionally, distribution bimodality of grain diameter is observed, when the most frequent grain-sizes concentrate in two fractions: psammitic fine-grained and aleuritic or psammitic medium-grained and aleuritic (Pl. I, Figs. 5, 6).[3]

The mean content of detrital quartz in sandstones in particular sections is commonly high; in the northern part of the area it ranges from 62.2% vol. (Parczew IG 10) to 91.6% vol. (Krowie Bagno IG 1), and in the southern part is between 65.0 to 80.0% vol. Commonly maximum quartz content is noted in arenites showing quartz overgrowths (Łopiennik IG 1, Bachus 1) and carbonate cement (Radzyń IG 8). A significant part of quartz grains is enveloped by thin overgrowth (regenerative) rims (Pl. I, Fig. 4; Pl. II, Fig. 9) or — under the presence of carbonate cement — is corroded (Pl. I, Fig. 7; Pl. II, Fig. 8). The above phenomena often do not allow to determine precisely the original shape and a degree of roundness of grains. Quartz individuals are characterized most often by uniform extinction, only sporadically undulating or mosaic, occasionally they contain small mineral inclusions. In-

[3] A method of determination of sorting based on the relationship between size of the maximum grain (d_{max}) and a size of the most frequent grain (d_f), is an approximate method, which generally biases classification of a studied rock towards poorer sorting categories. From visual examination of thin sections — representing uncomparably greater grain collection — one may conclude that Tremadoc sandstones are generally well sorted.

dividual quartzes with aggregate structure were also observed (Terebin IG 5, Chylin 2).

Illite and chlorite are principal components of pelitic fraction, accompanied in some places by quantitatively subordinate kaolinite. Illite commonly occurs in a form of dense fine flake aggregates, often difficult to identify in a microscope because of presence of a fine-dispersed, dark pigment composed of pyrite, leucoxene or iron hydroxides and oxides, an isotropic bituminous substance and phosphatic impregnations.

Qualitative mineral composition of rocks of sandstone group is complemented by authigenic minerals: cryptocrystalline silica forming either thin overgrowths on a part of quartz grains or patchy concentrations and impregnations, carbonates represented by calcite and/or dolomite, occasionally siderite, an isotropic phosphatic substance, and sulphides — mainly pyrite and marcasite.

Cement and/or matrix in sandstones is scarce, non-uniformly distributed and locally of a concretionary character. Matrix is composed of clayey-silty material, only exceptionally pure clay, whereas a proper (passive) cement is formed of carbonates — mostly calcite and/or dolomite (Pl. I, Figs. 6, 7; Pl. II, Fig. 8), phosphates (Pl. I, Fig. 5), authigenic quartz (Pl. I, Fig. 4; Pl. II, Fig. 9), silica and pyrite. Matrix content in quartz arenites does not exceed 10% vol., and a cement content is between 5.0 to 20.0% vol., while content of both matrix and cement in wackes ranges from 15.0 to 35.0% vol. and from 0.0 to 12.0% vol., respectively.

Lithology and petrography of the investigated transgressive sandstone sediments in the Lublin region reveals numerous analogies with their genetic equivalents in isochronous intervals from adjacent areas, including Podlasie Depression, Peribaltic Syneclise, and the substratum of the Carpathian foreland (Uszkowce 1, Uszkowce 4) in Poland (Z. Modliński, B. Szymański, 1972; B. Szymański, 1974; H. Tomczyk, 1962, 1963) and Wołyń–Podole Elevation and Lwów Depression in Ukraine (G. M. Pomianowska, A. V. Chiżniakov, 1972; W. A. Ginda, 1978).

SILTSTONES

Siltstones occur in most of the examined sections, mostly in a lower and middle portion of particular sections (Fig. 2). In the sections of the southern region and in Święcica 1 borehole they constitute from 20 to 30% of a total thickness studied. In remaining sections, siltstones does not exceed 20% of the total thickness, and in the borehole Radzyń IG 8 they were not found at all.

Investigated siltstones are compact and hard rocks displaying a variable — dominantly significant — degree of diagenesis. Their colour is monotonous: dominates gray or dark grey (Łopiennik IG 1, Bachus 1), subordinately gray-brown (Parczew IG 10, Wierzbica 1). A significant part of siltstones is intensely silicified, calcificated or locally pyritized and often impregnated by phosphates. Occasionally, siltstones rich in clayey substance show locally elevated organic matter content. The bulk of siltstones is indistinctly horizontally bedded, partly fractured and intersected by thin veins of carbonates and quartz. These rocks are characterized by a high degree of sorting and moderate rounding of detrital components. The mean size of the most frequent quartz grain (d_f) is 0.05 mm, and a maximum diameter (d_{max}) 0.12 mm. In siltstones individual burrows, current hieroglyphs and sediment-deformations occur, or they may be lacking any sedimentary structures.

The structure is aleuritic (Pl. II, Fig. 10; Pl. III, Figs. 12, 13), occasionally aleuritic-psammitic (Pl. III, Fig. 12), while a texture is homogeneous (Pl. II, Figs. 10, 11; Pl. III, Fig. 12) or, in rare cases, partly concretionary. Sporadically one can find an oriented texture — indistinctly horizontally layered (Pl. III, Fig. 13), underlain by a lamination: parallel, lenticular or slightly diagonal.

Siltstones form — similarly to sandstones — indistinct bedded units of two types: simple layers of uniform lithology and complex beds composed of gradational lithology, comprising a variable number of simple layers. The layer thickness in the first case ranges from 0.1 to about 0.6 m, while in the latter ranges from 0.7 to 1.5 m, exceptionally reaching 2.1 m (Terebin IG 5). Siltstones contact with adjacent rocks either with gradual transitions, or across sharp, slightly uneven surfaces. A part of the latter ones may be interpreted as surfaces associated with short-term episodes of non-deposition .

The group of siltstones is characterized by variable textural features. Examined samples of these rocks belong to two main lithologic types, i.e. quartz siltstones and clayey siltstones. A basic difference between these two consists in a different content of clay: insignificant in quartz siltstones (10–20% vol.), and significantly greater in clay siltstones (20–50% vol.). Typically rocks of these two types are macroscopically poorly contrasted and form numerous vertical transitions with indistinct and gradual boundaries. Variable content of clay does not always allow to pinpoint a sharp boundary between quartz siltstones and clayey siltstones. The quartz siltstone is more important in terms of thickness in sections of the northern region whereas the latter one — in sections of the southern region.

Qualitative and quantitative mineral and chemical composition of siltstones is similar to that of sandstones as described above. Quartz siltstones, occasionally display a greater content of micas and clay minerals when compared to the sandstones. Clay siltstones, on the other hand, contain commonly significantly more clay, forming a matrix (Pl. II, Fig. 11). As a result, the clay siltstones are typically less compact than quartz siltstones or sandstones.

CLAYSTONES

Claystones are represented in majority of examined sections, forming mainly a middle or an upper part of particular sequences. They significantly dominate in terms of thickness in sections of the southern part of the region and in two sections of the northern area (Krowie Bagno IG 1, Bachus 1), where they constitute between 30 to 50% of the studied thickness. In remaining sections, claystone content does not exceed 20% of the total thickness, and in Parczew IG 10 and Tarkawica 1 boreholes they were not found at all (Fig. 2).

Claystones are cohesive rocks, typically hard and intensively altered diagenetically. Their colour is uniform: gray and dark gray, locally with dark brown hue. Typically they are macroscopically lacking distinctive layering, or they display irregular flat lamination accentuated by parallel alignment of micaceous minerals and quartz silt or sand grains. In claystones sedimentologic structures occur commonly, including bioturbation, current hieroglyphs and sediment-deformation. Significant part of claystones is intensively silicified, calcificated or pyritized, often impregnated by phosphates. Claystones poor in coarser detrital material often — particularly in the southern region — show elevated content of organic matter (i.e. dark microlithofacies in a sense of A. Langier-Kuźniarowa, 1971, 1993). Claystone structure is pelitic (Pl. III, Fig. 15) or pelitic-aleuritic (Pl. III, Fig. 14), texture homogeneous or partly oriented, tabular or wavy laminated.

A group of claystones is characterized by poor textural features. Examined samples belong to three main lithologic types, i.e. proper claystones, bituminous claystones and silty claystones. A basic difference between them consist in a different content of a coarser detrital material being insignificant in bituminous claystones (2.0–3.0% vol.) and in proper claystones (3.0–15.05% vol.), and distinctly greater in silty claystones (15.0–50.0% vol.). Typically rocks of the above claystone types are macroscopically poorly contrasted and form numerous vertical transitions, and indistinct to gradual boundaries. Variable amount of coarser detrital material in their composition does not always allow to pinpoint a sharp boundary between claystones and silty claystones, and between these and clayey siltstones. The first two types clearly dominate in terms of thickness in sections of the southern region, and the last one — in sections of the northern region.

A clay fraction is composed mainly of illite and chlorite, which are occasionally accompanied by kaolinite and mixed-layer minerals(?). Grains are composed mainly of quartz of silt fraction, insignificant quantities of micas — mostly muscovite, and — in trace amounts — biotite, feldspars and accessory minerals. Mineral composition is complemented by carbonates, silica, phosphates, more rarely pyrite, glauconite and organic matter.

Coarser grains of detrital material are well-sorted and poorly or only partly rounded. The mean size of the most frequent quartz grain (d_f) is 0.04 mm, and the maximum size (d_{max}) reaches value of 0.07 mm, exceptionally 0.09 mm. Coarser detrital material may be uniformly distributed in a rock clayey groundmass, or locally forms more abundant concentrations in a form of laminae, streaks or bands of irregular shapes and vague outlines.

CARBONATE ROCKS

Carbonate rocks are rare and volumetrically subordinate lithologic type in the Tremadoc sequence. They were found in borehole sections Łopiennik IG 1, Busówno IG 1, Bachus 1, Wierzbica 1 and Horodło 1, where they occur in middle and upper part of the sequence. Typically they form distinct isolated interbeds of an uniform or gradually changing lithology and their thickness ranges from about 0.12 m (Horodło 1) to 0.4–0.6 m (Busówno IG 1, Łopiennik IG 1). Prevailing majority of these interbeds occurs among siltstones, exceptionally they accompany sandstones (Horodło 1). Their boundaries with adjacent clastic rocks are clear and distinct, often with a slightly uneven base of a sedimentary discontinuity type (Łopiennik IG 1). Number of carbonate interbeds in particular section varies and ranges from one (Horodło 1) to five (Łopiennik IG 1), with their total thickness of 0.12 and about 1.5 m, respectively (Fig. 2). Carbonate rocks constitute about 0.5 to 4.0% of a total thickness of the studied Tremadoc sequence (Horodło 1, Łopiennik IG 1).

Chemical composition of representative samples of carbonate rocks from selected boreholes is presented in Tab. 2.

Lithologic development of carbonate interbeds is rather uniform. They are mostly composed of intensively recrystallized limestones with unclear or poorly preserved primary depositional structures, displaying identical mineral composition and similarity of structural and textural parameters in particular sequences.

One may conclude from microscopic analyses that mainly marly limestones and dolomitic limestones are represented among carbonates, with insignificant contribution of limestones and sandy limestones. Their petrographic character corresponds to three basic textural types in a sense of R. L. Folk (1959), i.e. sparites, clayey sparites, and sparse biosparites. Quantitative relationships between these three types vary; most frequently clayey sparites and/or sparites dominate (60%) being locally accompanied by typically subordinate intercalations of biosparites (30%). These rocks are macroscopically poorly contrasted and their mutual transitions are gradual and vague. It is difficult to exactly trace boundaries between the described types. Macroscopically these are mostly massive rocks, compact and hard, partly more or less silicified. They typically do not display a distinct layering, or they display occurrence of vaguely defined irregular bands or streaks. Their colour is gray or dark gray, occasionally — depending on a type and quantity of admixture of clayey material partly bright or darker (Wierzbica 1). In limestones, present are characteristic, uneven surfaces of sedimentary discontinuities with thin clayey covers, poorly developed stylolites of various origins, and also small fractures and irregular veins filled with quartz or pyrite. Structure is allotriomorphic (grained), texture — massive, unoriented or locally vaguely streaked.

Qualitative and quantitative mineral composition of the limestones is poorly diversified. Their groundmass forms a mosaic of mutually interlocking xenomorphic individuals of calcite and/or dolomite of a diameter 0.3 to 4.1 mm, among which locally characteristic recrystallization "fan-like" structures of calcite occur (Pl. IV, Fig. 19; Pl. V, Fig. 21). Significant part of grains and crystals of calcite displays polysynthetic twinning and small fractures. Occasionally they display features indicating influence of a dynamic metamorphism.

Allochemical material is mainly composed of three basic components: of clayey minerals (5.0–20.0% vol.) — including illite and chlorite, detrital quartz (1.0–15.0% vol.) and

Table 2

Chemical composition of limestones in the Tremadoc of the Lublin region (weight %)

Well	Depth [m]	CaO	MgO	CO_2	MnO	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	Na_2O	K_2O	P_2O_5	Sc	Total
Lopiennik IG 1	4420.8	44.73	0.70	33.30	0.18	13.74	0.41	3.79	0.42	0.58	0.12	0.92	0.05	0.15	99.09
Łopiennik IG 1	4427.4	40.83	1.07	30.00	0.23	20.14	0.27	4.00	0.32	1.51	0.14	0.95	0.05	0.17	99.68
Wierzbica 1	2236.4	42.82	0.94	37.80	0.20	10.00	0.21	3.50	0.42	0.62	0.16	0.96	1.07	0.20	98.90
Wierzbica 1	2237.0	36.16	4.02	38.12	0.26	9.80	0.32	3.70	1.12	3.24	0.20	0.85	0.85	047	99.11
Niwa 1	1121.3	43.50	1.75	38.80	0.27	5.21	0.36	3.40	0.60	1.10	0.30	0.80	0.55	0.42	97.06

biogenic material (0.0–15.0% vol.), which are mutually mixed and occur in variable quantitative proportions. Bioclastic grains are represented by small fragments of biogenic structures and/or their partly recrystallized relicts whose size ranges from 0.2 to 0.6 mm. They are distributed without preferred orientation and non-uniformly: occasionally they form more abundant concentrations in biosparites, while locally they are lacking in sparites. Taxonomic composition of a biogenic material includes mostly fragments of benthic organisms: brachiopods, crinoids, ostracods, conodonts(?), gastropods, bryozoans(?) and small fragments of unidentified taxa (varia). Biogenic components content in specific types of rocks is variable: in sparites and clayey sparites it reaches up to 4.0%, and in biosparites it reaches maximum 16.0% vol. (Wierzbica 1, depth 2236.9 m; Busówno IG 1, depth 2943.3 m).

In a group of components of allogenic origin, variable quantities of clayey minerals occur (ca. 3.0–20% vol.), mostly illite and chlorite, detrital quartz of aleuritic and psammitic fraction (0.0–7.5% vol.), chalcedony and — in trace amounts — sericitized small grains of feldspar and glauconite. Quartz grains are well-rounded and poorly sorted. Commonly, grains of psammitic fraction display significantly better degree of rounding than grains of aleuritic fraction (Pl. V, Figs. 20, 21, 22). The mean size of a most frequent quartz grain (d_f) is 0.07 mm, and maximum (d_{max}) is 0.22 mm. Occasionally grain size distribution is bimodal and a category of the most frequent grains belongs to two fractions; aleuritic and psammitic fine-grained or aleuritic and psammitic medium-grained. Part of detrital grains of quartz — mostly in a psammitic fraction — is characterized by traces of corrosion caused by carbonates, occasionally is covered by thin rims of secondary quartz or phosphate rims (Pl. V, Figs. 21, 22). Sporadically the following characteristic features occur in these rocks: jagged concentrations of dark brown isotropic bituminous matter, authigenic chlorite forming locally fine platy aggregates, pleochroic fine flaky biotite and impregnations and patchy concentrations of iron hydroxides and oxides, phosphates, siderite and sulphides — mostly pyrite.

Suite of sedimentological and textural features, and also position of carbonate intercalation in a sequence indicates that they may be interpreted as storm coquinas (M. E. Tucker, 1995). According to this approach their bioclastic material was transported by storm currents from near-shore zones of a basin or intrabasinal shoals at a time of intermittent catastrophic processes (storms, hurricanes), causing short-term episodes of increased water energy (R. G. Walker, 1978; E. L. Simpson, A. Eriksson, 1990).

Carbonate rocks of Tremadoc in the Lublin region show numerous, lithological-petrological and sedimentological analogies with their genetic equivalents in isochronous horizons of the western part of Peribaltic Syneclise (Z. Modliński, B. Szymański, 1997).

SILICEOUS ROCKS

Chalcedonites were found in the upper part of Busówno IG 1 section (depth 2941.0–2941.4 m) where they form locally developed horizon with distinct and sharp boundaries: with claystones at the base, and with transgressive sequence of lower Arenig glauconitite at the top (Fig. 2). Siliceous rocks in the Tremadoc of the Busówno IG 1 section comprise 1.5% of its total thickness.

Siliceous rocks are massive, dense and very hard, fat and slippery to the touch, with a characteristic smooth conchoidal fracture surfaces. Their colour is gray and light gray, in parts with celadon or slightly bluish hue. Chalcedonites lack macroscopically detectable bedding. Their significant parts are fractured and intersected by thin veins and veinlets composed of quartz, carbonates (Pl. V, Fig. 23), occasionally pyrite. Part of these structures — mostly those parallel to original stratification — may be considered as syneresis cracks, associated with dehydration and lithification of originally loose silica gel. Structure of chalcedonites is micro- and cryptocrystalline, whereas texture is non-oriented, in places indistinctly banded with clayey material (Pl. V, Fig. 23).

Qualitative mineralogical composition of siliceous rocks is rather uniform. The groundmass is formed of mosaic of recrystallized micro- and cryptocrystalline silica — mostly in a form of chalcedony, in which spherulitic recrystallizated structures locally occur. Grained detrital material is represented in trace amounts (< 3% vol.) or it may be lacking. It is represented by individual grains of detrital quartz of silt fraction, small, commonly sericitized clasts of feldspars, clays (illite, chlorite), exceptionally muscovite and pale fine aggregate grains of glauconite. The following biogenic components were determined: fine fragments of phosphate-chitinous brachiopod shells, fragments of sponge spicules, ostracods, jagged fragments of graptolite rhabdosomes and taxonomically unidentified organic structures. Mineral composition of the rock is complemented by authigenic minerals: isotropic concentrations of a brown phosphate substance, calcite microsparite, iron hydroxides and oxides and pyrite.

Distribution of grain components in the chalcedony groundmass of the rock is chaotic. Clay admixture locally forms more abundant concentrations in a form of elongated, often discontinuous bands and stripes, occasionally lenticular and with vague contours. In such cases clay minerals content is commonly so significant, that the rocks may be considered as clayey cherts. Occurrence of elevated content of phosphates and bituminous matter, which commonly form small indistinct concentrations, is locally associated with concentrations of clayey substance.

Qualitative mineral and chemical composition of siliceous rocks, their textural and sedimentological features, finally their position in a sequence indicate that they formed as result of a direct precipitation of siliceous gel from sea water. Their origin may be associated with a short-term episode of crisis of clastic sedimentation near the end of a regressive stage of Tremadoc sedimentation development.

Chalcedonites in Busówno IG 1 section are identical or similar in terms of their appearance and lithologic-petrographic character to chalcedonites of the Lower Ordovician in the Kielce region of the Holy Cross Mountains, described from the Bardo Syncline (Zalesie Nowe–Chojnów Dół, Wysoczki, Szumsko, Biesak quarry) and vicinity of Zbrza, among others by M. Turnau-Morawska (1958), W. Bednarczyk (1966), and W. Trela (1998). According to W. Bednarczyk (1981, 1996) they represent the lower part of the upper Tremadoc (Ceratopyge A_{III}) or the upper Tremadoc–lowest Arenig, i.e. siltstone and chalcedonites from Zbilutka (chalcedonite formation from Wysoczki as described by J. Dzik and A. Pisera, 1994), while according to J. Znosko and R. Chlebowski (1976) they are of the early Arenig age (Latorp B_I). A distinct attribute of the latter in comparison to chalcedonites of the Busówno IG 1 section is a typically significant content of pyroclastic material (R. Chlebowski, 1971, 1976, 1996).

DIAGENETIC FEATURES

Examined Tremadoc sediments, particularly sandstones and siltstones, are generally strongly diagenetically altered rocks. Post-depositional processes, played a significant role in a final development of their textural features and mineral composition. Interpreted diagenetic processes include compaction, pressure dissolution, cementation — silicification and carbonate cementation, to a smaller degree phosphatization, chloritization, sericitization and pyritization. A significant part of these diagenetic transformations was associated with three different periods of the sediment geologic history: a stage of an early diagenesis and stages of early and late epigenesis respectively. Processes of early and late epigenesis affected with a variable intensity the Tremadoc sediments in the whole sequence, however, a stage of early epigenesis is mainly limited to top intervals which directly contact with pre-Arenig surface of sedimentary unconformity. Range and scale of diagenetic transformations vary spatially from more intensive in the southern region (area of Krasnystaw–Hrubieszów), to relatively weaker in northern region (area of Kock–Chełm Lubelski).

Three types cementation processes, i.e. silicification, phosphatization and carbonate cementation played the basic role in diagenesis of Tremadoc sediments. Their effects are seen in almost all samples of sandstones, majority of siltstones, and part of limestones and claystones.

Silicification processes typically are associated with two stages: early diagenesis and early epigenesis. Development of quartz overgrowths (authigenic quartz of the first generation) is associated with silicification processes of the first of the described stages, however, quartz void-filling cement (authigenic quartz of a second generation) is associated with later stage.

Early diagenetic silicification process resulted in formation of quartz cement as quartz overgrowths on detrital quartz, mainly of a psammitic fraction, in sandstones and partly in quartz siltstones. In extreme cases rocks composed of almost 100% of quartz were formed, with a microscopic mosaic texture typical for quartzites (Pl. I, Fig. 4). Contacts between idiomorphic grains are most often straight, concave-convex, more rarely suture-like; however, original contacts between detrital grain surfaces of these grains are pointed, and occasionally grains do not contact. Thus, it may be assumed that the main silicification process occurred under poorly advanced mechanical compaction, i.e. during early diagenesis. It was associated with more or less long-term direct contact of the deposited material with sea water rich in SiO_2. An intensive process of early diagenetic silicification does not always lead to a complete pore-filling. The cementation continued in a stage of epigenesis, when sediments were buried at a significant depth and intensification of chemical compaction processes occurred. A pressure dissolution process of quartz in overlying strata was an important factor (M. T. Heald, G. F. Baker, 1977). Released silica may have further crystallized in still empty pore spaces, forming the authigenic quartz of the second generation. Microstructure of quartz crystals of the second generation is commonly observed locally in larger pores, suggesting their centripetal growth. Filling up by authigenic crystals of second generation quartz of some of the pores and open fractures, typically parallel to original stratification is associated also with a phase of late epigenetic silicification. Some forms of microstylolites, and perhaps single suture intragranular contacts (Łopiennik IG 1, depth 4458.0 m) may be considered as manifestation of dissolution processes.

Described cementation processes are complemented by phosphatization process associated with early diagenesis. It became pronounced by forming thin isotropic rims commonly enveloping detrital quartz sand grains in sandstones and siltstones (Pl. II, Fig. 8) and locally by impregnation within clayey or clayey-silty cement (Pl. I, Fig. 5). Its origin was associated with calcium phosphate precipitation directly from marine waters or interstitial solutions in the sediment. Typically, manifestations of early diagenetic phosphatization are more intensive in the parts of clastic rocks indicating presence of microsparitic cement and loosely packed grain framework. Therefore, it may be assumed that phosphate cementation occurred in an early stage of diagenesis, accompanied by a very weak mechanical compaction. Based on the fact that phosphate rims on quartz grains do not occur around grains with quartz overgrowths it may be supposed that early diagenetic process of phosphatization occurred slightly earlier than or simultaneously with early diagenetic silicification.

Formation of diagenetic carbonates is another, besides silification, widely and intensely manifested cementation process. Its main phase occurred during early diagenesis and early epigenesis after the main stage of silicification. Carbonate cementation processes are exemplified by a formation of microsparitic cement and numerous veins and veinlets of calcite and/or dolomite, occasionally of chemical composition of siderite and ankerite. Occurrence of pseudomorphs of carbonates after quartz, feldspars and glauconite, and corrosion of numerous grains of quartz, occasionally feldspars, glauconite and bioclasts is also associated with carbonate precipitation.

Evidence of mineral replacement, including chloritization, sericitization and pyritization, was observed in many parts of clastic rocks. An intensive process of chloritization was noted in bottom interval of the sections Łopiennik IG 1 (depth 4460.0 m), Busówno IG 1 (depth 2964.0 m) and Bachus 1 (depth 3031.5 m) among others, where numerous chloritic pseudomorphs after glauconite, chloritized micas and partly feldspars are present. Grains of feldspars and glauconite were subjected to early silicification and carbonate cementation.

Pyrite in the studied rocks occurs in various forms: from small irregular concentrations and impregnations, locally forming cement (sandstones, quartz siltstones), to idiomorphic crystals and structures visible only under a microscope, as framboidal spherical grains in claystones. Authigenic pyrite often locally replaces chitinous-phosphate matter of bioclasts, exceptionally it forms thin rims around quartz grains.

Poorly cohesive sandstones occur in upper intervals of many sections particularly in the northern region where their original textural features were subjected to alteration caused by destructive epigenetic processes of pre-Arenig weathering under subaerial conditions. It was manifested by a partial or total secondary removal of mainly carbonate cement, and formation of ferruginous cement composed of iron hydroxides and oxides. Distinct reduction of sandstone cohesiveness and, in places, increase of their porosity are commonly associated with pre-Arenig decementation process. All hydrocarbon shows detected so far in an upper interval of the Tremadoc sequence (Święcica 1, Wierzbica 1, Horodło 1) are to be referred to the sandstones subjected to pre-Arenig decementation process.

A complex of described changes mostly represents lockomorphic stage of diagenesis, which is characteristic for lithification processes associated with mineral replacement (G. Larsen, G. V. Chilingar, 1967).

High values of an index of intergranular contacts, defined as the mean number of contacts with neighbouring grains in a thin section representative for one grain of a rock, indicates a high degree of diagenesis of the Tremadoc sediments. The mean values of the index are variable for specific types of sandstone groups, typically higher for quartz arenites (5–7) particularly in the southern region, and lower for wackes (4–5). Mean values of the index for sandstones as a whole in particular sections range from 3.2 to 4.6, maximum values are 6.3 (Radzyń IG 8).

Commonly observed in thin sections is a presence of microzones of deformed structure, which may be explained as related to tectonic stresses. These are: slickenside surfaces with squeezed and pulverized quartz grains and deformed clayey laminae, zones of dynamically deformed quartz grains displaying distinctly wavy and banded light extinction, finally system of irregular microfractures. These structures are locally accompanied by minute veinlets of chlorite and concentrations of kaolinite, iron hydroxides and oxides and sulphides. From the presence of microzones of deformed structure it may be concluded that the studied rocks were subjected to significant — at least locally — tectonic stress and perhaps influenced by low-temperature thermal processes.

LITHOFACIES

The investigated sections can be grouped into two categories differing in lithology, textural character, sedimentary structures inventory, and thickness of the Tremadoc sedi-

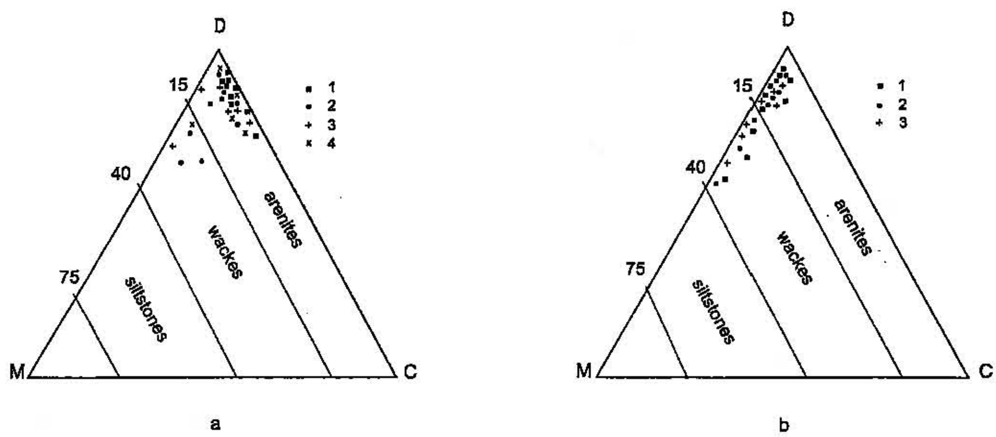

Fig. 3. Petrographic composition of Tremadoc sandstones and siltstones in the Lublin region (triangular diagram according to F. L. Schwab, 1977)
C — cement (chemical cement), D — detrital material, M — matrix; boreholes: a: 1 — Radzyń IG 8, 2 — Wierzbica 1, 3 — Krowie Bagno IG 1, 4 — Bachus 1; b: 1 — Łopiennik IG 1, 2 — Terebin IG 5, 3 — Horodło 1

Skład petrograficzny piaskowców i mułowców tremadoku Lubelszczyzny (trójkąt klasyfikacyjny według F. L. Schwaba, 1977)
C — cement (spoiwo chemiczne), D — materiał detrytyczny, M — matrix; otwory wiertnicze: a: 1 — Radzyń IG 8; 2 — Wierzbica 1, 3 — Krowie Bagno IG 1, 4 — Bachus 1; b: 1 — Łopiennik IG 1, 2 — Terebin IG 5, 3 — Horodło 1

ments. First group, displaying more uniform lithology, may be assigned to the sandstone lithofacies, the remaining one — to siltstone-claystone lithofacies. The sandstone lithofacies occurs in the northern region (Kock–Chełm Lubelski area), and siltstone-claystone lithofacies in the southern one (Krasnystaw–Hrubieszów area). Zone of interfingering of these lithofacies runs approximately diagonally from SE to NE (Fig. 1).

Deposits of the sandstone lithofacies represent medium- and fine-grained sandstones of a quartz arenite type (~ 60%), mostly with carbonate cement, and siltstones (30%) — mostly quartz siltstones — and silty claystones (~10%). Quantitative importance of the last two lithologic groups gradually increases toward south and south-west. As indicated by biostratigraphic data, the lithofacies comprises only the lower Tremadoc sediments (Pakerort A_{II}). The incomplete sediment thickness ranges from 0.2 m (Parczew IG 10) to about 28.0 m (Busówno IG 1).

Lithologic record of the siltstone-claystone lithofacies consists of claystones (40%), mostly clayey siltstones (30%), and fine- to medium-grained sandstones (30%). The bulk of claystones is composed of rocks poor in coarser detrital material and bituminous to a various degree, whereas among the siltstones, typically clayey siltstones prevail. Sandstones comprise mostly wackes, particularly fine-grained, and locally also sublithic wackes (Łopiennik IG 1, Terebin IG 5). Importance of claystones gradually increases toward south and south-west. From biostratigraphic data it may be concluded that the sedimentary sequence comprises the lower Tremadoc (Pakerort A_{II}) and locally the upper Tremadoc (Ceratopyge A_{III}). The incomplete sediment thickness ranges from 26.0 m (Horodło 1) to 43.0 m (Łopiennik IG 1).

A set of sedimentological features of sediments of the distinguished lithofacies indicates that their deposition occured in an open, shallow shelf basin with a gently floor inclined towards south-west. Sediments of the sandstone lithofacies represent a typical sequence of a proximal part of the shelf, whereas siltstone-claystone lithofacies — a deeper-water environment and more distant from a shore-line. Their common feature is, among others, that they reflect alternation of a narrow spectrum of environments, related to interference of two different factors, i.e. global one represented by eustatic fluctuations of a sea level and regional — associated with tectonic activity of basement blocks.

Based on sedimentary structures inventory and other qualitative characteristics of the sediments, it may be concluded that deposition occurred — in general sense — in two types of hydrodynamic conditions: below a normal wave base and episodically — within a range of influence of storm wave base (R. G. Walker, 1978; J. C. Harms *et al.*, 1982). The presence of the latter was associated with strong storms and related currents in a near-shore zone, which reached the Lublin region being loaded with suspended material, which was subsequently deposited from waning currents. Their activity is manifested, among others, by numerous intraformational erosional surfaces, accompanied occasionally by beds of intraformational conglomerates, coquinas, individual clasts and graded bedding in some intervals of sandstones.

A relative Tremadoc sedimentation rate was significant and spatially differentiated: higher in a distal part of the shelf (area of Krasnystaw–Hrubieszów), and about two times lower in a proximal part (area of Kock–Chełm Lubelski). A zone of the maximum thickness of an order of 100 m in the area of Biłgoraj (Narol IG 2, Dyle IG 1) indicates (Z. Modliński, 1993) that the rate was consequently increasing toward south-west, i.e. in a direction of the Teisseyre-Tornquist line (T-T). A rate of sedimentation was extremely non-uniform, with episodically repeating — more or less long-term — periods of non-deposition or clastic sedimentation crises, manifested as surfaces of synsedimentary unconformity of a simple hardground type[4], intra- and interbed scour surfaces, limestone beds and locally siliceous chalcedonites.

The major episodes of relatively long-term non-deposition are associated with the boundaries Tremadoc/Upper Cambrian and Tremadoc/Arenig, which mark phases of emersion and subaerial conditions. The early and late Tremadoc non-deposition is related to a widespread regression, which was caused, in the case of the former event, by the pronounced uplift during the Holy Cross tectonic phase and eustatic low-stand associated with so-called Peltocare regressive event (PRE) (R. M. Erdtmann, 1986), whereas in the case of the latter event, by an uplift during the Sandomierz phase and eustatic lowstand due to so-called Ceratopyge regressive event (CRE) (R. M. Erdtmann, 1986). Two significant phenomena are associated with the latter period of non-deposition: process of intensive erosion, which in many areas removed entire thickness of Tremadoc sediments or its significant part, and a change of climatic conditions and shift in sedimentation from clastic (Tremadoc) to glauconite-carbonate (Arenig).

Intra-Tremadoc episodes of non-deposition can be interpreted as relatively short-term and mostly caused by regional tectonic movements of the basement blocks. They were manifested significantly more intensively in a regressive sequence segment (upper part of the lower Tremadoc–upper Tremadoc) than in a transgressive one (lower part of upper Tremadoc). Their geologic record is represented by numerous intra- and interbed scours, occasionally accompanied by layers of intraformation conglomerate, finally by a simple hardground surfaces.

The geologic record of intra-Tremadoc non-depositional events does not provide evidence for their duration or subaerial exposition.

There is a lack, among others, of structures indicating any subaerial corrosion or oxydation, vadose structures, desiccation cracks etc.

Frequency and widespread occurrence of non-depositional episodes suggest that the Tremadoc time interval in the Lublin is largely represented by non-deposition.

The main part of the Tremadoc sediments has numerous features typical for sediments deposited under conditions of well-oxidized waters. A significant part of a distal shelf zone (area of Krasnystaw–Hrubieszów) is locally represented by clayey rocks, more or less bituminous and poor in coarser detrital material. They represent so-called dark microlithofacies according to A. Langier-Kuźniarowa (1971, 1993). Their origin may be associated with a presence of locally deeper-water conditions, with waters periodically stagnant and poorly aerated, with tendencies towards low-oxygene conditions. Phenomena of anoxia and water stratification were possibly caused by topography of the basin floor, predetermined by tectonic movements of the basement blocks. Basically similar bathymetric conditions may have controlled the origin of siliceous rocks, found in the Busówno IG 1 borehole, whose origin is moreover associated with an episode of lacking or insignificant transport of detrital material and elevated concentrations of gel-like substances rich in SiO_2 in bottom waters. They were deposited below a storm wave base, in a quiet environment of distal part of the shelf with moderately good aeration of bottom waters. Periodically occurring slightly elevated turbulence is manifested by locally gentle lamination of chalcedonites and their enrichment in a fine-grained detrital material. Chalcedonites formed probably under conditions of a distinct decrease of detrital material transport in a regressive stage of the basin development.

Analysis of distribution of incomplete thicknesses of Tremadoc sediments and a relative content of medium-grained sandstones in particular sections leads to a conclusion that transport occurred from two basic directions: from the north-east and from the east. Uplifted parts of the East European Craton located in the east and south-east (Belorussian–Ukrainian Land), where older clastic rocks of the Vendian–Cambrian were subjected to intensive erosion, may be regarded as probable source areas. Advanced degree of rounding, sorting and mineral maturity of the detrital material indicates reworking of older clastic sediments and a long path of transport in a near-shore zone of the Tremadoc basin. Here, the sediment, experienced frequently repeated sedimentation and resuspension due to synsedimentary scouring as a result of activity of waves and tides.

SUMMARY AND CONCLUSIONS

The results of macroscopic, microscopic and chemical analyses of clastic-carbonate sediments of the Tremadoc in the eastern Lublin region lead to the following general conclusions:

1. The Tremadoc succession is represented in the studied sections by sediments of the lower Tremadoc (Pakerort A_{II}) and locally upper Tremadoc (Ceratopyge A_{III}), the latter found in the upper part of the section in the borehole Łopiennik IG 1 (K. Lendzion *et al.*, 1979; Z. Modliński, 1993). The succession disconformably overlies, with a significant stratigraphic gap, the Middle Cambrian sandstones of *Eccaparadoxides oelandicus* or *Paradoxides paradoxissimus* Zones (K. Lendzion, 1983*a*, *b*), and is commonly overlain by transgressive conglomerate-glauconitic or glauconite-carbonate sediments of the lower Arenig (Latorp B_I).

2. The Tremadoc is mostly composed of clastic rocks, among which conglomerates, medium- and fine-grained oligomictic quartz sandstones, siltstones and claystones are present. Of secondary importance are locally occurring intercalations of limestone and siliceous rocks of chalcedonite type (Busówno IG 1).

[4] A group of these unconformities may be classified as simple hard grounds with a single discontinuity surface as described by K.P. Krajewski (1981). Their basic diagnostic features are: slightly uneven, non-levelled surface, a poor inventory of lithoclasts and bioclasts, lack of traces of organic activity and lack of neither early-diagenetic non-carbonate mineralization nor clear indications of subaqueous chemical corrosion.

3. Basal conglomerates are replaced laterally by oligomictic vari- and medium-grained quartz sandstones with individual, small exoclasts. A package of these rocks forms a trangressive member of the Tremadoc succession, which formed in a near-shore environment of quickly transgressing epicontinental marine basin.

4. Examined samples of sandstones belong in majority to quartz arenites. Subordinately — mainly in sequences of the southern region — they are represented by quartz wackes, and only exceptionally in a basal part — by sublithic wackes (Terebin IG 5, Łopiennik IG 1). Sandstones, particularly arenites, are commonly mineralogically and structurally mature or very mature.

5. Examined sediments of the Tremadoc, particularly sandstones and siltstones, have undergone generally intense diagenetic alterations including compaction, pressure dissolution, cementation — silicification and carbonization, to a smaller degree phosphatization, chloritization, sericitization and pyritization. These processes caused a significant reduction of the high initial porosity of the studied rocks.

6. Lateral variability of Tremadoc sediments results in occurrence of two lithofacies units: sandstone lithofacies (Kock–Chełm Lubelski area) and siltstone-claystone lithofacies (Krasnystaw–Hrubieszów area). General lithology and sedimentological features of the distinguished lithofacies indicate that they represent a typical sequences of an open shelf: sandstone lithofacies — a proximal part, while siltstone-claystone lithofacies — a distal part, more deep-water and more distant from a shore.

7. Based on analysis of distribution of incomplete thicknesses of Tremadoc sediments and a relative contribution of medium-grained sandstones in particular sections, it may be concluded that transport of the material occurred from two basic directions: from the north-east and from the east.

8. High degree of rounding, sorting and mineralogical maturity of the detrital material indicates a long transport path. Clastic material of Tremadoc sediments in the Lublin region originated in great majority as a result of reworking of older complexes of clastic rocks of the Vendian–Cambrian. In a near-shore zone it was subjected to a long transport and repeated sedimentation, resuspension, synsedimentary erosion and redeposition related to activity of tides and waves.

9. A complex of Tremadoc rocks has numerous features typical for so-called lower transgressive platform terrigenous association according to W. J. Chain (1974), typical for areas of old, stable platforms and formed during relatively tectonically quiet periods in surrounding mobile zones.

Acknowledgements. A manuscript has been reviewed by R. Dadlez and Z. Modliński, whom I sincerely thank for the critical comments. I would also like to express my deep gratitude and thanks to the Management and Geologists of the Oil and Gas Exploration Enterprise in Wołomin, particularly to Dr. F. Stolarczyk, whose courtesy enabled me to use core samples and other information.

Translated by Marek Matyjasik

REFERENCES

BEDNARCZYK W. (1966) — Lithology of the Lower Ordovician (Oelandian) in the Kielce region of the Holy Cross (in Polish with English summary). Mts. Biul. Geol. Wydz. Geol. UW, **8**, p. 4–53.

BEDNARCZYK W. (1981) — Stratygrafia ordowiku Gór Świętokrzyskich. Przew. 43 Zjazdu Pol. Tow. Geol., p. 35–41.

BEDNARCZYK W. (1996) — Stopień rozpoznania systemu ordowickiego w obszarze Gór Świętokrzyskich. W: Paleozoik na tle budowy skorupy ziemskiej w Górach Świętokrzyskich. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

CHAIN W. J. (1974) — Geotektonika ogólna. Wyd. Geol. Warszawa.

CHLEBOWSKI R. (1971) — Petrography of the Ordovician deposits of the Bardo syncline in the southern part of the Świętokrzyskie Mts. Arch. Miner., **29**, p. 193–304, no. 1/2.

CHLEBOWSKI R. (1976) — Petrographic study of early Paleozoic tuffogenic rocks from the Holy Cross Mts. (in Polish with English summary). Arch. Miner., **34**, p. 69–134, no. 1.

CHLEBOWSKI R. (1996) — Litologia ordowiku w Górach Świętokrzyskich. W: Paleozoik na tle budowy skorupy ziemskiej w Górach Świętokrzyskich. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

DZIK J., PISERA A. (1994) — Sedimentation and fossils of the Mójcza Limestone. In: Ordovician carbonate platform ecosystem of the Holy Cross Mountains (ed. J. Dzik *et al.*). Palaeont. Pol., **53**, p. 5–51.

ERDTMANN R. M. (1986) — Early Ordovician eustatic cycles and their bearing an punctuations in early nematophorid (planctic) graptolite evolution. In: Global bio-events (ed. O. M. Walliser), **8**.

FOLK R. L. (1959) — Practical petrographic classification of limestones. Bull. Am. Ass. Petrol. Geol., **43**, p. 1–38, no. 1.

FOLK R. L. (1968) — Petrology of sedimentary rocks. The University of Texas. Austin.

FRIEDMAN G. M. (1959) — Identification of carbonate minerals by staining methods. J. Sed. Petrol., **29**, p. 87–97, no. 1.

FRIEDMAN G. M. (1971) — Staining. In: Procedures in sedimentary petrology. Wiley-Interscience, p. 511–530.

GRADZIŃSKI R., KOSTECKA A., RADOMSKI A., UNRUG R. (1986) — Sedymentologia. Wyd. Geol. Warszawa.

GINDA W. A. (1978) — O paleogeografii Wolyno-Podolskoj plyty w ordowikskom periodie. In: Geologiczeskoe stroienie prowincii goriuczich iskopaemych Ukrainy, p. 73–81. Izd. Naukowo Dumka. Kiew.

HARMS J. C., SOUTHARD J. B., WALKER R. G. (1982) — Structures and sequences in clastic rocks. Soc. Econ. Pal. Min., Short Course 9, Calgary, **251**.

HEALD M. T., BAKER G. F. (1977) — Diagenesis of the Mt. Simon and Rose Run sandstones in western West Virginia and southern Ohio. J. Sed. Petrol., **47**, p. 6–77, no. 1.

KRAJEWSKI K. P. (1981) — Pelagic stromatolites from the High-Tatric Albian Limestones in the Tatra Mts (in Polish with English summary). Kwart. Geol., **25**, p. 731–751, no. 4.

LARSEN G., CHILINGAR G. V. (1967) — Diagenesis in sediments. Elsevier. Amsterdam–London–New York.

LANGIER-KUŹNIAROWA A. (1971) — New data on petrography of the Ordovician and Silurian of the Polish Lowland (in Polish with English summary). Biul. Inst. Geol., **245**, p. 253–351.

LANGIER-KUŹNIAROWA A. (1993) — Charakterystyka petrograficzna skał ordowiku. W: Budowa geologiczna starszego paleozoiku południowo-wschodniej Lubelszczyzny (ed. Z. Modliński), p. 139–161. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

LENDZION K. (1971) — Kambr. W: Dokumentacja wynikowa otworu strukturalno-parametrycznego Białopole IG 1. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

LENDZION K. (1975*a*) — Krowie Bagno IG 1. Kambr. W: Profile głęb. otw. wiert. Inst. Geol., z. 25. Warszawa.

LENDZION K. (1975*b*) — Kambr. W: Dokumentacja wynikowa otworu parametryczno-strukturalnego Busówno IG 1. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

LENDZION K. (1976) — Kambr. W: Dokumentacja wynikowa otworu Łopiennik IG 1. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

LENDZION K. (1983*a*) — The development of the Cambrian platform deposits in Poland (in Polish with English summary). Pr. Inst. Geol., **105**.

LENDZION K. (1983*b*) — Biostratigraphy of the Cambrian deposits in the Polish part of the East-European Platform (in Polish with English summary). Kwart. Geol., **27**, p. 669–691, no. 4.

LENDZION K., MODLIŃSKI Z., SZYMAŃSKI B. (1979) — The Tremadocian of the Lublin Region (in Polish with English summary). Kwart. Geol., **23**, p. 713–725, no. 4.

MIGASZEWSKI Z., NARKIEWICZ M. (1983) — Identification of common carbonate minerals with the use of colouring indices (in Polish with English summary). Prz. Geol., **31**, p. 258–261, no. 4.

MODLIŃSKI Z. (1975) — Ordowik. W: Dokumentacja wynikowa otworu badawczego Parczew IG 10. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

MODLIŃSKI Z. (1984*a*) — Stratygraphy of post-Tremadocian Ordovician rocks in the Lublin region (in Polish with English summary). Kwart. Geol., **28**, p. 1–12, no. 1.

MODLIŃSKI Z. (1984*b*) — Ordowik. Przew. 46 Zjazdu Pol. Tow. Geol., p. 131–134.

MODLIŃSKI Z. (1993) — Ordowik. W: Budowa geologiczna starszego paleozoiku południowo-wschodniej Lubelszczyzny (ed. Z. Modliński), p. 45–59. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

MODLIŃSKI Z., SZYMAŃSKI B. (1972) — The Lower Tremadocian in the region of Lidzbark Warmiński (in Polish with English summary). Kwart. Geol., **16**, p. 274–288, no. 2.

MODLIŃSKI Z., SZYMAŃSKI B. (1997) — The Ordovician lithostratigraphy of the Peribaltic Depression (NE Poland). Geol. Quart., **41**, p. 273–288, no. 3.

PETTIJOHN F. J., POTTER P. E., SIEVER R. (1972) — Sand and sandstone. Springer-Verlag. Berlin–Heidelberg–New York.

POMIANOWSKA G. M., CHIŻNIAKOV A. V. (1972) — Ordowikske otłożenia jugo-zapadnoj okrainy Ruskoi platformy. In. Paleontologija, geologija i poleznyje iskopaemyje Moldawii. Wyp. 2, p. 42–54. Kiszyniew.

SCHWAB F. L. (1977) — Grandfather Mountain Formatiom: Depositional environment, provenance, and tectonic selting of late Precambrian alluvium in the Blue Ridge of North Carolina. J. Sed. Petrol., **47**, p. 800–810, no. 2.

SIMPSON E. L., ERIKSSON K. A. (1990) — Early Cambrian progradational and transgressive sedimentation patterns in Virginia: an example of the early history of a passive margin. J. Sed. Petrol., **60**, p. 84–100, no. 1.

SZYMAŃSKI B. (1974) — Tremadocian in the Peribaltic Depression (in Polish with English summary). Kwart. Geol., **18**, p. 223–242, no. 2.

TOMCZYK H. (1962) — Stratygrafia osadów staropaleozoicznych z wiercenia w Uszkowcach koło Lubaczowa. W: Księga pamiątkowa ku czci profesora Jana Samsonowicza, p. 123–146. Wyd. Geol. Warszawa.

TOMCZYK H. (1963) — Ordovician and Silurian in the basement of the Fore-Carpathian Depression (in Polish with English summary). Rocz. Pol. Tow. Geol., **33**, p. 289–320, no. 3.

TRELA W. (1998) — Środowiska sedymentacji utworów starszego paleozoiku. Ordowik. Centr. Arch. Geol. Państw. Inst. Geol. Warszawa.

TUCKER M. E. (1995) — Sedimentary petrology. Blackwell Scientific Publications.

TURNAU-MORAWSKA M. (1958) — Chalcedonites and associated rocks of the Tremadoc in the Holy Cross Mountains (Central Poland). Petrographic study. Rocz. Pol. Tow. Geol., **27**, p. 169–194, no. 1/4.

WALKER R. G. ed. (1978) — Facies models. Geoscience Canada.Toronto.

ZNOSKO J. (1998) — Mapa tektoniczna Polski w skali 1:500 000. Warszawa.

ZNOSKO J., CHLEBOWSKI R. (1976) — Revision of the Lower Ordovician stratigraphy in the Holy Cross Mts. (Central Poland) (in Polish with English summary). Rocz. Pol. Tow. Geol., **46**, p. 135–152, no. 1/2.

CHARAKTERYSTYKA PETROLOGICZNA I LITOFACJALNA EPIKONTYNENTALNEJ SEKWENCJI KLASTYCZNEJ TREMADOKU NA OBSZARZE LUBELSKIM

Streszczenie

Przedstawiono wyniki badań litologicznych, petrograficznych i chemicznych transgresywno-regresywnej serii osadów tremadoku Lubelszczyzny, które stwierdzono w 17 otworach wiertniczych wykonanych w latach 1968–1992 przez Instytut Geologiczny i Zjednoczenie Górnictwa Naftowego oraz Gazownictwa (ZPGN-Wołomin). Zespół skalny profilów jest reprezentowany przez osady tremadoku dolnego (pakerort A_{II}) oraz lokalnie tremadoku górnego (ceratopyge A_{III}), za który uznano część przystropową sekwencji w otworze wiertniczym Łopiennik IG 1 (K. Lendzion *et al.*, 1979; Z. Modliński, 1993). Kompleks osadów tremadoku leży niezgodnie ze znaczną luką stratygraficzną na środkowokambryjskich piaskowcach poziomu *Eccaparadoxides oelandicus* lub *Paradoxides paradoxissimus* (K. Lendzion, 1983*a*, *b*), a w stropie przykryty jest powszechnie przez transgresywne utwory zlepieńcowo-glaukonitowe lub glaukonitowo-węglanowe arenigu dolnego (latorp B_{I}) (Z. Modliński, 1984*a*, *b*).

Zespół skalny transgresywno-regresywnej serii tremadoku Lubelszczyzny składa się w przeważającej mierze ze skał silikoklastycznych. Zupełnie podrzędny udział przypada skałom nieterygenicznym: węglanom (wapienie, wapienie dolomityczne) i skałom krzemionkowym (chalcedonity). Zasadniczą część członu klastycznego sekwencji tworzą zlepieńce, oligomiktyczne piaskowce średnio- i drobnoziarniste, mułowce i iłowce. Piaskowce reprezentowane są głównie przez arenity kwarcowe o zwartym szkielecie ziarnowym. Skały piaskowcowe o cechach teksturalnych wak występują podrzędnie — głównie w profilach południowej części regionu. Udział mułowców i iłowców jest zróżnicowany przestrzennie: nieznaczny w północnej części regionu (rej. Kocka–Chełma Lubelskiego), a relatywnie większy w części południowej (rej. Krasnegostawu–Hrubieszowa). Osady tremadoku — w szczególności piaskowce i mułowce — są na ogół intensywnie zdiagenezowane. Istotną rolę w ostatecznym ukształtowaniu ich cech teksturalnych oraz składu mineralnego odegrały procesy postdepozycyjne, w tym zwłaszcza diagenetyczne: kompakcja, rozpuszczanie pod ciśnieniem, cementacja — sylifikacja i karbonatyzacja, w mniejszym stopniu fosfatyzacja oraz zastępowanie — chlorytyzacja, serycytyzacja i pirytyzacja. Zespół tych procesów spowodował znaczną redukcję ich pierwotnie wysokiej porowatości inicjalnej. Za sprawą zmienności obocznej w serii osadów tremadoku manifestuje się istnienie dwu jednostek litofacjalnych o odmiennej rejonizacji: litofacji piaskowcowej (rej. Kocka–Chełma Lubelskiego) i litofacji mułowcowo-ilastej (rej. Krasnegostawu–Hrubieszowa). Jakościowy charakter litologii i zbiór cech sedymentologicznych osadów wyróżnionych litofacji wskazuje, że reprezentują one typowe sekwencje szefu otwartego (R. G. Walker, 1978; J. C. Harms *et al.*, 1982): litofacja piaskowcowa — części proksymalnej, natomiast litofacja mułowcowo-ilasta — części dystalnej bardziej głębokowodnej i bardziej oddalonej od brzegu. Ich cechą wspólną jest m.in. to, że charakteryzują się zmiennym, naprzemianległym występowaniem wąskiego spektrum środowisk, których sukcesja związana była z działaniem dwu odmiennych genetycznie czynników: globalnego — wyrażonego eustatycznymi wahaniami poziomu wód oceanu światowego — oraz regionalnego — związanego z aktywnością tektoniczną bloków podłoża.

Z analizy rozkładu niepełnych miąższości osadów tremadoku i względnego udziału piaskowców średnioziarnistych w poszczególnych profilach wynika, że dostawa materiału następowała z dwu podstawowych kierunków:

z NE ku SW oraz z E ku W. Zaawansowany stopień obtoczenia, wysortowania i dojrzałości mineralnej materiału detrytycznego wskazuje na długą drogę transportu. Jest to wynikiem głównie dwu czynników: po pierwsze — materiał okruchowy osadów tremadoku lubelskiego pochodził w zdecydowanej większości z redepozycji starszych serii skał klastycznych wendo-kambru; po drugie — w strefie przybrzeża zbiornika tremadockiego poddany był długiemu transportowi i intensywnej obróbce mechanicznej, ulegając wielokrotnie sedymentacji, suspensji, erozji synsedymentacyjnej i przemieszczeniu w rezultacie działania pływów i falowania.

Zespół transgresywnych osadów zlepieńcowo-piaskowcowych tremadoku Lubelszczyzny wykazuje liczne koneksje litologiczno-petrograficzne z genetycznymi ich ekwiwalentami w równowiekowych profilach obszarów sąsiednich, m.in. obniżenia podlaskiego, perybałtyckiego i podłoża Przedgórza Karpat w Polsce (Z. Modliński, B. Szymański, 1972; B. Szymański, 1974) oraz wyniesienia wołyńsko-podolskiego i zapadliska lwowskiego na Ukrainie (G. M. Pomianowska, A. W. Chiżniakow, 1972; W. A. Ginda, 1978).

EXPLANATIONS OF PLATES

PLATE I

Fig. 4. Medium-grained quartz sandstones (quartz arenite) with a quartz overgrowth cement. Lower Tremadoc (Pakerort A_{II}). Bachus 1, depth 3012.8 m, crossed nicols

Piaskowiec kwarcowy średnioziarnisty (arenit kwarcowy) o kwarcowym spoiwie regeneracyjnym. Tremadok dolny (pakerort A_{II}). Bachus 1, głęb. 3012,8 m, nikole skrzyżowane

Fig. 5. Vari-grained quartz sandstone (quartz arenite) with phosphate and phosphate-clayey cement. Lower Tremadoc (Pakerort A_{II}). Parczew IG 10, depth 1496.3 m, one nicol

Piaskowiec kwarcowy różnoziarnisty (arenit kwarcowy) o spoiwie fosforanowym i fosforanowo-ilastym. Tremadok dolny (pakerort A_{II}). Parczew IG 10, głęb. 1496,3 m, bez analizatora

Fig. 6. Medium-grained quartz sandstone (quartz arenite) with a carbonate cement, visible pyritized grains of phosphates. Lower Tremadoc (Pakerort A_{II}). Bachus 1, depth 3012.9, one nicol

Piaskowiec kwarcowy średnioziarnisty (arenit kwarcowy) o spoiwie węglanowym; widoczne ziarna spirytyzowanych fosforanów. Tremadok dolny (pakerort A_{II}). Bachus 1, głęb. 3012,9 m, bez analizatora

Fig. 7. Medium-grained quartz sandstone (quartz arenite) with a carbonate cement; visible pyritized grains of phosphates. Lower Tremadoc (Pakerort A_{II}). Wierzbica 1, depth 2241.0 m, crossed nicols

Piaskowiec kwarcowy średnioziarnisty (arenit kwarcowy) o spoiwie węglanowym; widoczne ziarna spirytyzowanych fosforanów i bioklastów. Tremadok dolny (Pakerort A_{II}). Wierzbica 1, głęb. 2241,0 m, nikole skrzyżowane

PLATE II

Fig. 8. Medium-grained quartz sandstone (quartz arenite) with a carbonate cement. Lower Tremadoc (Pakerort A_{II}). Parczew IG 10, depth 1496.35 m, one nicol

Piaskowiec kwarcowy średnioziarnisty (arenit kwarcowy) o spoiwie węglanowym. Tremadok dolny (pakerort A_{II}). Parczew IG 10, głęb. 1496,35 m, bez analizatora

Fig. 9. Medium-grained quartz sandstone (sublithic arenite) with a quartz overgrowth cement; note the lithoclast of phosphatized siltstone. Upper Tremadoc (Ceratopyge A_{III}). Łopiennik IG 1, depth 4422.4 m, one nicol

Piaskowiec kwarcowy średnioziarnisty (arenit sublityczny) o kwarcowym spoiwie regeneracyjnym; widoczny litoklast mułowca sfosfatyzowanego. Tremadok górny (ceratopyge A_{III}). Łopiennik IG 1, głęb. 4422,4 m, bez analizatora

Fig. 10. Siltstone with a few quartz sand-grains; concentrations of carbonates locally visible. Upper Tremadoc (Ceratopyge A_{III}). Łopiennik IG 1, depth 4421,7 m, one nicol

Mułowiec z ziarnami kwarcu frakcji psamitowej; widoczne partiami skupienia węglanów. Tremadok górny (ceratopyge A_{III}). Łopiennik IG 1, głęb. 4421,7 m, bez analizatora

Fig. 11. Clayey siltstone. Lower Tremadoc (Pakerort A_{II}). Bachus 1, depth 3014.8 m, one nicol

Mułowiec ilasty. Tremadok dolny (pakerort A_{II}). Bachus 1, głęb. 3014,8 m, bez analizatora

PLATE III

Fig. 12. Siltstone — a contact between clayey siltstone and quartz siltstone. Lower Tremadoc (Pakerort A_{II}). Łopiennik IG 1, depth 4422.8, one nicol

Mułowiec — kontakt mułowca ilastego i mułowca kwarcowego. Tremadok dolny (pakerort A_{II}). Łopiennik IG 1, głęb. 4422,8 m, bez analizatora

Fig. 13. Clayey siltstone — a contact between clayey siltstone and claystone. Lower Tremadoc (Pakerort A_{II}). Busówno IG 1, depth 2944.2, one nicol

Mułowiec ilasty — kontakt mułowca ilastego i iłowca. Tremadok dolny (pakerort A_{II}). Busówno IG 1, głęb. 2944,2 m, bez analizatora

Fig. 14. Bituminous silty claystone. Lower Tremadoc (Pakerort A_{II}). Wierzbica 1, depth 2240.5 m, one nicol

Iłowiec mułowcowy bitumiczny. Tremadok dolny (pakerort A_{II}). Wierzbica 1, głęb. 2240,5 m, bez analizatora

Fig. 15. Bituminous claystone. Lower Tremadoc (Pakerort A_{II}). Wierzbica 1, depth 2241,0 m, one nicol

Iłowiec bitumiczny. Tremadok dolny (pakerort A_{II}). Wierzbica 1, głęb. 2241,0 m, bez analizatora

PLATE IV

Fig. 16. Silicified claystone. Lower Tremadoc (Pakerort A_{II}). Łopiennik IG 1, depth 4423.5 m, one nicol

Iłowiec skrzemionkowany. Tremadok dolny (pakerort A_{II}). Łopiennik IG 1, głęb. 4423,5 m, bez analizatora

Fig. 17. Laminated claystone. Lower Tremadoc (Pakerort A_{II}). Wierzbica 1, depth 2237.5 m, one nicol

Iłowiec laminowany. Tremadok dolny (pakerort A_{II}). Wierzbica 1, głęb. 2237,5 m, bez analizatora

Fig. 18. Limestone (sparite). Lower Tremadoc (Pakerort A_{II}). Wierzbica 1, depth 2236.4 m, crossed nicols

Wapień (sparyt). Tremadok dolny (pakerort A_{II}). Wierzbica 1, głęb. 2236,4 m, nikole skrzyżowane

Fig. 19. Limestone (sparite); visible "fan-like" calcite structures. Upper Tremadoc (Ceratopyge A_{III}). Łopiennik IG 1, depth 4420.7 m, one nicol

Wapień (sparyt); widoczne struktury „wachlarzowe" kalcytu. Tremadok górny (ceratopyge A_{III}). Łopiennik IG 1, głęb. 4420,7 m, bez analizatora

PLATE V

Fig. 20. Marly limestone with detrital quartz. Lower Tremadoc (Pakerort A_{II}). Łopiennik IG 1, depth 4427.4 m, one nicol

Wapień marglisty z detrytycznym kwarcem. Tremadok dolny (pakerort A_{II}). Łopiennik IG 1, głęb. 4427,4 m, bez analizatora

Fig. 21. Limestone with quartz silt lamina. Lower Tremadoc (Pakerort A_{II}). Łopiennik IG 1, depth 4427.6 m, one nicol

Wapień z laminą kwarcu frakcji aleurytowej. Tremadok dolny (pakerort A_{II}). Łopiennik IG 1, głęb. 4427,6 m, bez analizatora

Fig. 22. Limestone (sparite) with quartz sand grain. Lower Tremadoc (Pakerort A_{II}). Wierzbica 1, depth 2236.7 m, one nicol

Wapień (sparyt) z ziarnami kwarcu frakcji psamitowej. Tremadok dolny (pakerort A_{II}). Wierzbica 1, głęb. 2236,7 m, bez analizatora

Fig. 23. Siliceous rock (chalcedonite); calcite veinlet visible. Lower Tremadoc (Pakerort A_{II}). Busówno IG 1, depth 2941.2 m, one nicol

Skała krzemionkowa (chalcedonit); widoczna żyłka kalcytu. Tremadok dolny (pakerort A_{II}). Busówno IG 1, głęb. 2941,2 m, bez analizatora

Photographs made by J. Modrzejewska from the Polish Geological Institute, Warszawa

Fotografie wykonała J. Modrzejewska z PIG, Warszawa

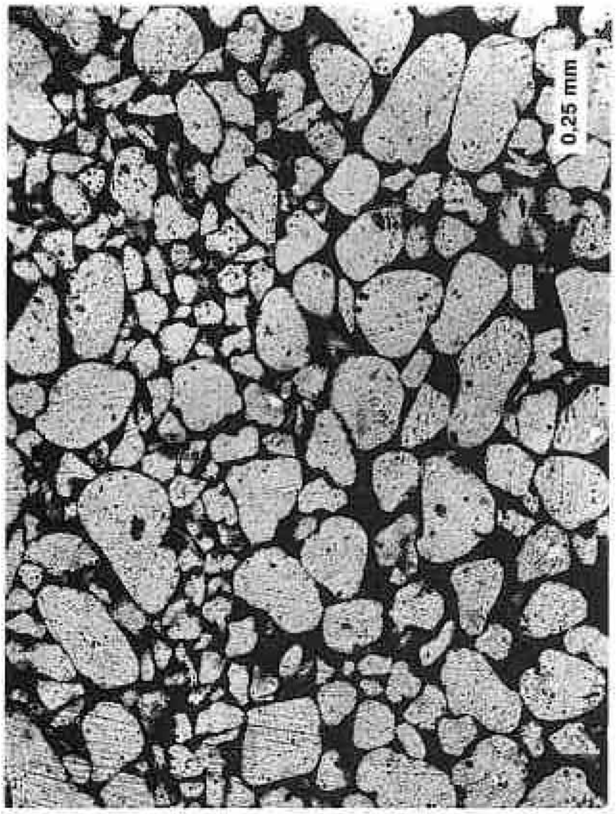

Fig. 5

Fig. 7

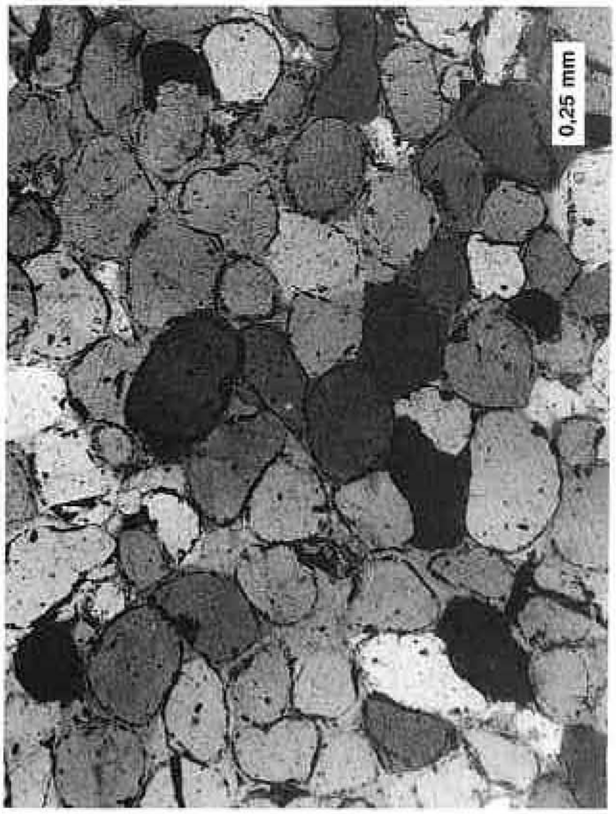

Fig. 4

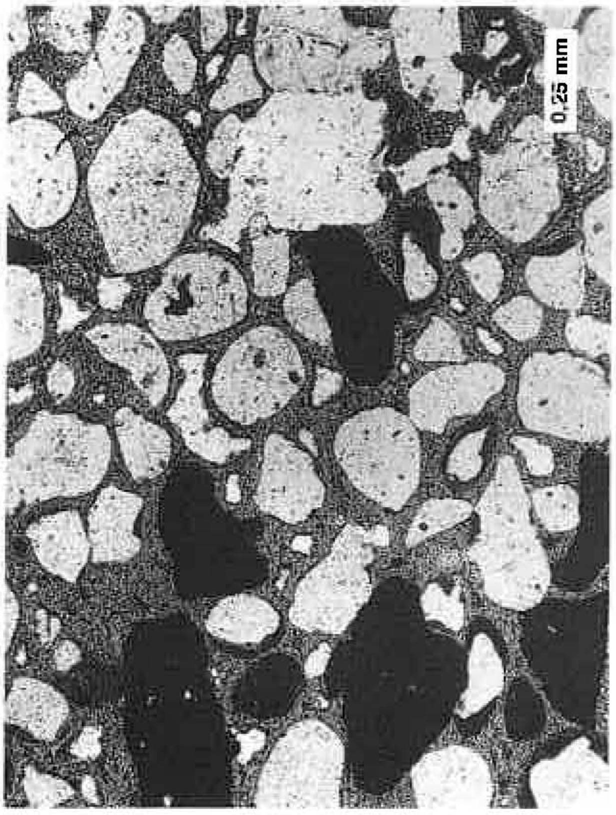

Fig. 6

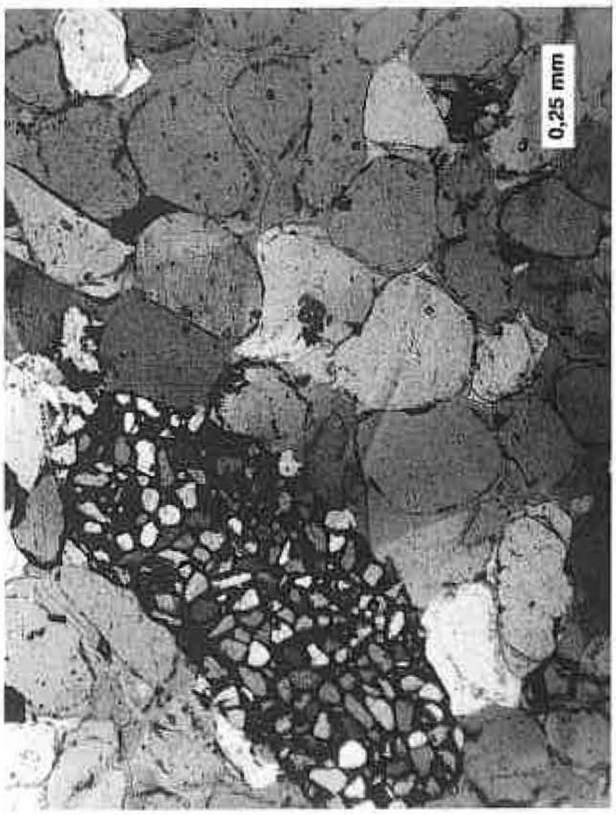

Fig. 9

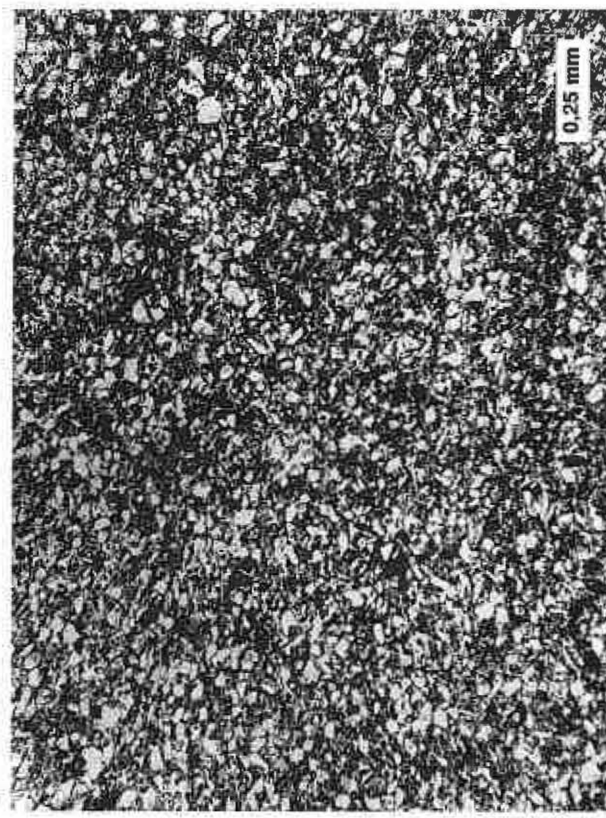

Fig. 11

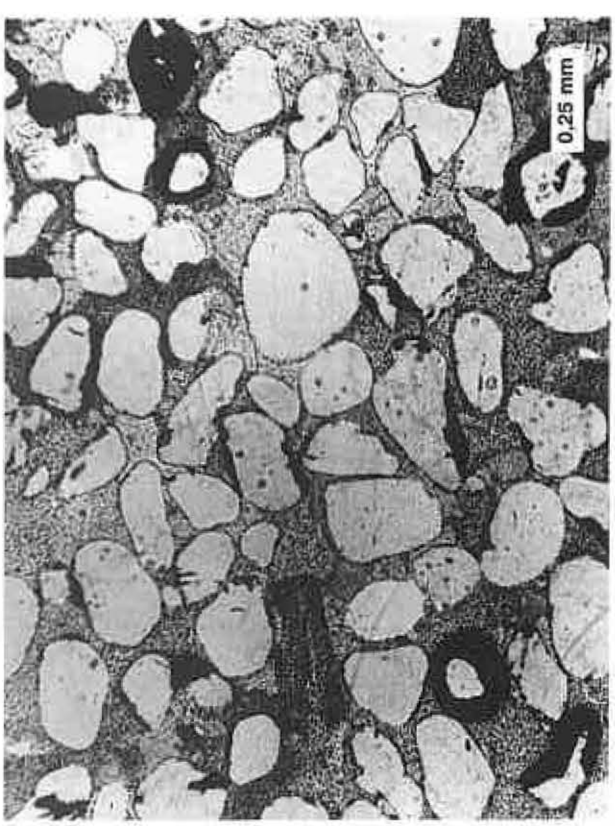

Fig. 8

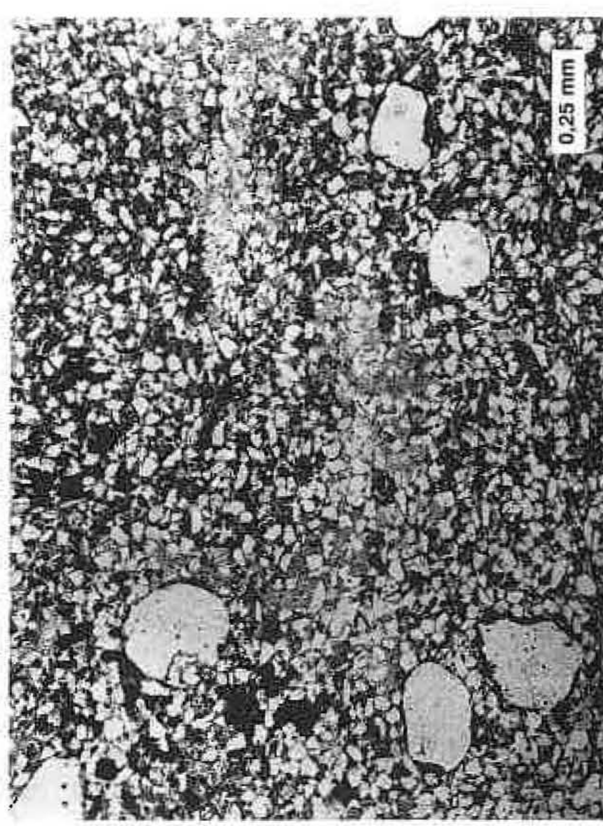

Fig. 10

Geol. Quart., 1998, **42** (4)

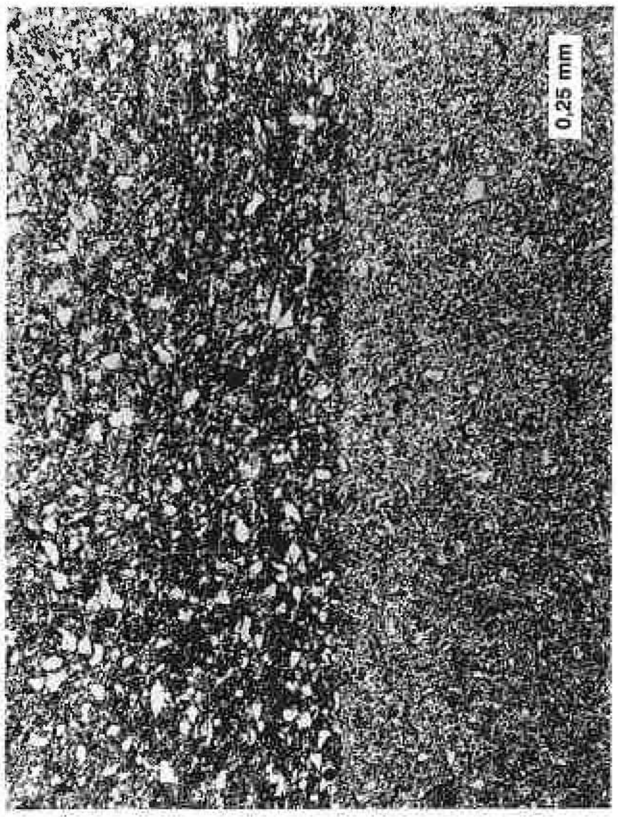

Fig. 13

Fig. 15

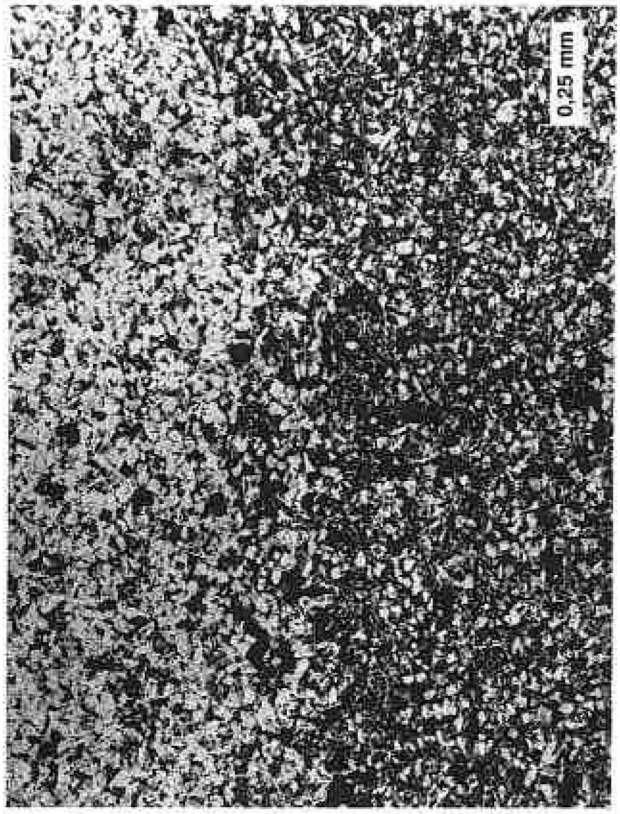

Fig. 12

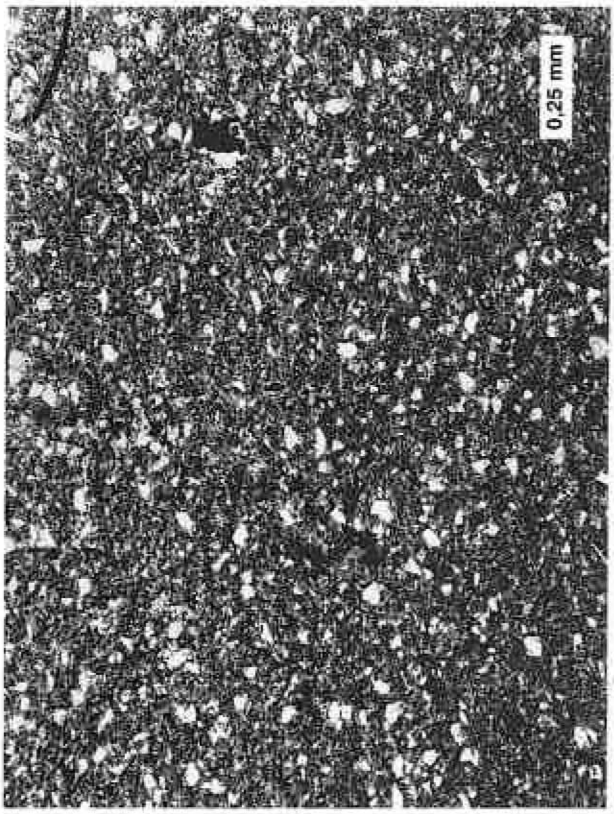

Fig. 14

Bronisław SZYMAŃSKI — Petrology and lithofacies of the Tremadoc epicontinental-marine siliciclastic sequence in the Lublin area (SE Poland)

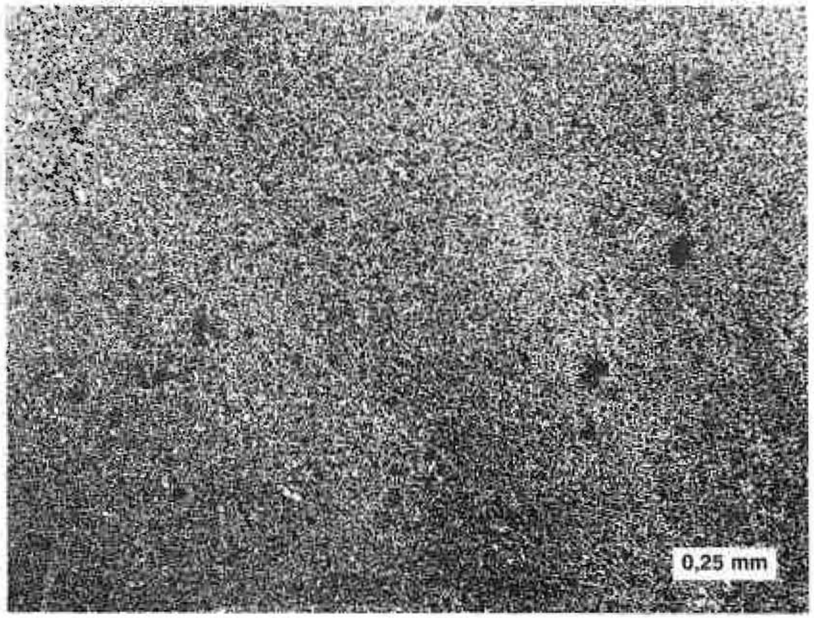

Fig. 16

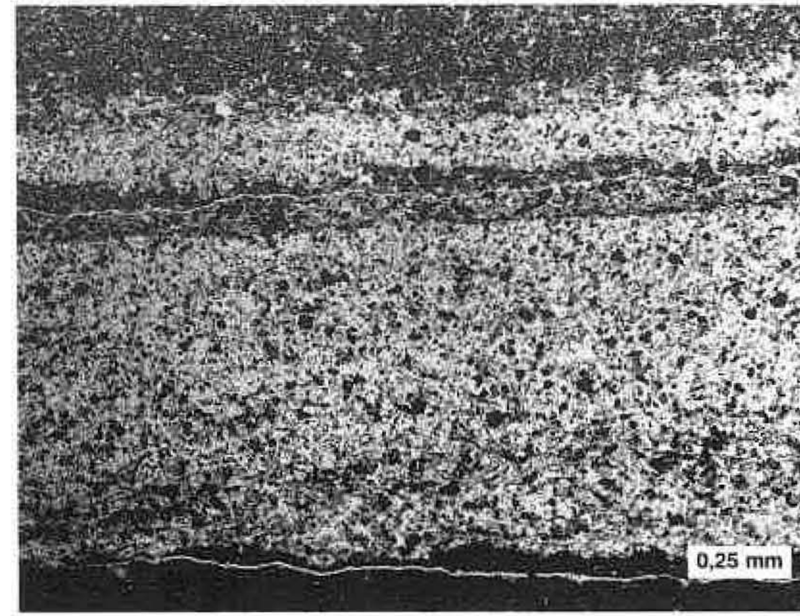

Fig. 17

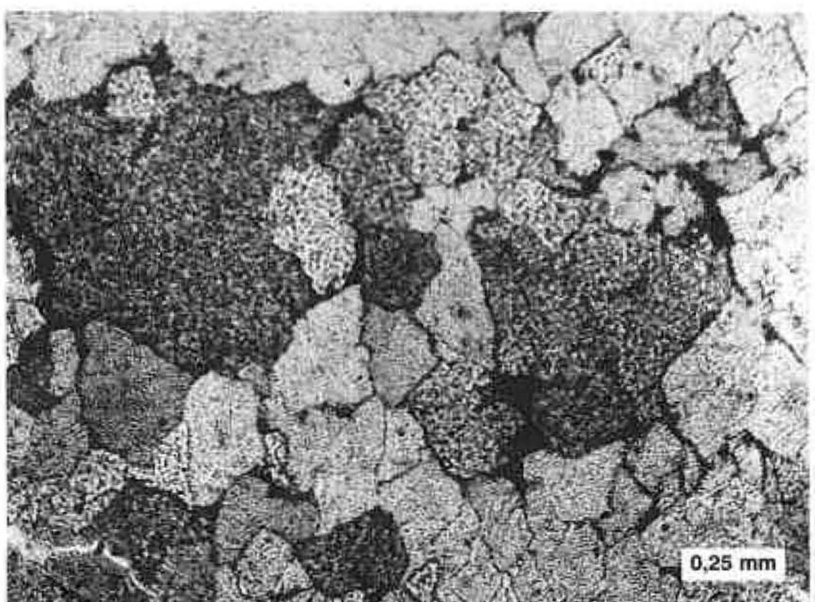

Fig. 18

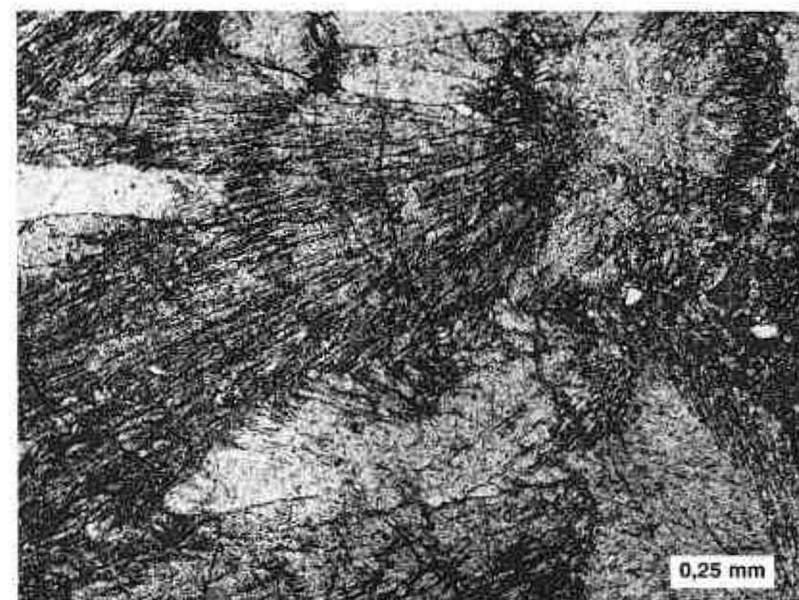

Fig. 19

PLATE IV

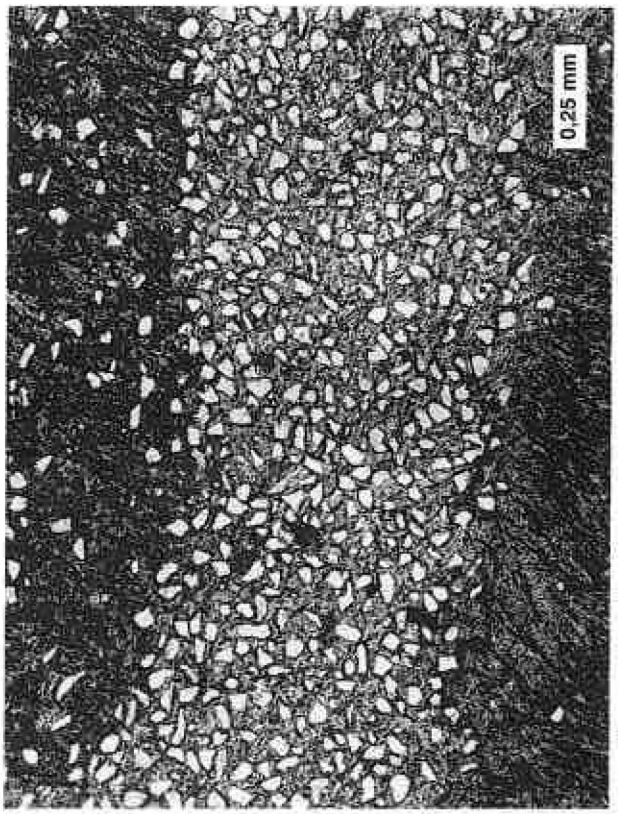

Fig. 21

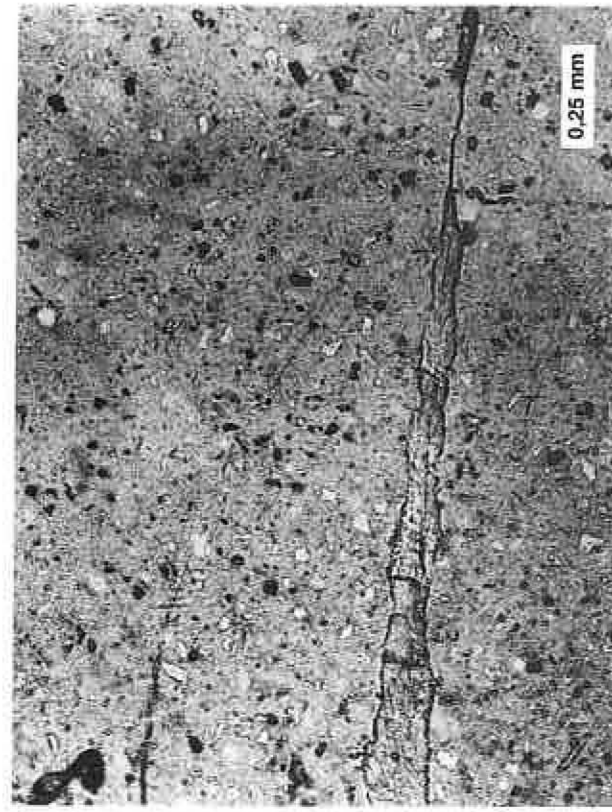

Fig. 23

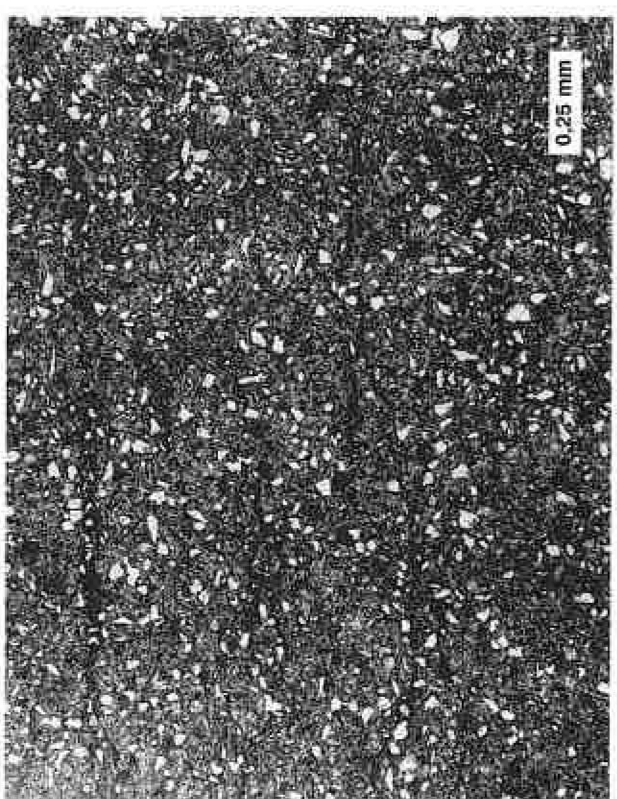

Fig. 20

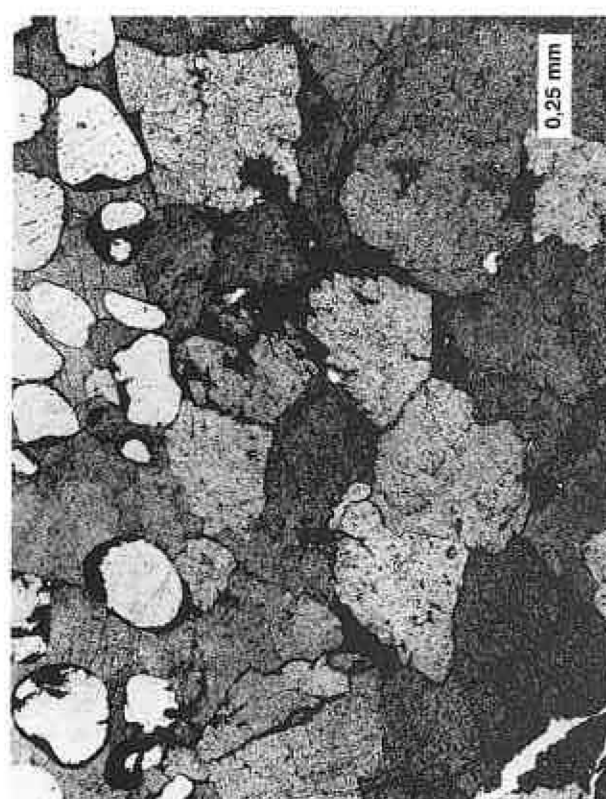

Fig. 22