Geological Quarterly, Vol. 40, No. 1, 1996, p. 65–88

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Devonian stratigraphy and depositional environments in proximity of the Sub-Carpathian Arch: Lachowice 7 well, southern Poland

The Devonian interval in the Lachowice 7 deep well section has been subdivided into six lithostratigraphic units representing probable Upper Emsian (unit A), Middle Devonian (units B and C) to almost entire Frasnian (units D–F). Middle to Upper Devonian facies are interpreted as deposited in proximal or central parts of an attached carbonate platform or ramp. Correlations with sections situated to the north support earlier concepts of southward shallowing of depositional environments towards the Sub-Carpathian Arch. At the same time, patterns of thickness and facies changes suggest that the Devonian basin extended at least few tens of kilometres to the south of the present erosional edge beneath the Carpathian thrust sheets.

INTRODUCTION

In southeastern Poland, the Devonian is represented by the epicontinental sequence of Lower Devonian terrigenous clastics overlain by marine carbonate and marly deposits usually ascribed to the Middle and Upper Devonian. Earlier investigations have documented gradual wedging out of carbonate and marly depositional units parallelled by shallowing of their sedimentary environments southwards, i.e. towards the Carpathians (M. Narkiewicz, 1978; M. Narkiewicz, G. Racki, 1987). Below the Carpathian overthrusts the Devonian deposits rest either upon the thin Cambrian clastics or directly on the metamorphosed Precambrian rocks. The latter build the elevated part of the triangle-shaped rigid crustal block in the substrate of the Upper Silesian Coal Basin, named the Cieszyn Massif or Block by S. Bukowy (1971). Clearly, this elevation, labelled here the Sub-Carpathian Arch, played a major role during the Palaeozoic palaeogeographic development in southern Poland. In particular, the Devonian deposition has been influenced by this relatively stable elevated

area while its post-Variscan i.e. post-Early Carboniferous erosion is responsible for the present southern limit of the Devonian rocks as shown on Figure 1.

The aim of the present paper is to extend earlier interpretations of the Devonian depositional environments in the Olkusz–Zawiercie and Dębnik areas to the southernmost subcrop area below the Carpathian thrust sheets, in proximity of the Sub-Carpathian Arch. The present study became possible owing to the Polish Oil and Gas Company which recently drilled several deep wells in vicinity of Sucha Beskidzka town. One of the wells, Lachowice 7, displaying fairly representative and relatively complete Devonian section, has been investigated in detail for the purposes of the present study.

Acknowledgements. I wish to express my sincere gratitude to Tadeusz Wilczek M. Sc. (Deputy Director of the Geological Office GEONAFTA, Warszawa) and Dr. Eugeniusz Jawor (Deputy Director of Exploration and Drilling Companies — Kraków) for making this study possible by releasing core material and other geological information. Dr. Władysław Moryc (Head of the Geological Office GEONAFTA, Kraków) is gratefully acknowledged for providing addditional information on the geology of the sub-Carpathian Palaeozoic. Prof. Elżbieta Turnau (Polish Academy of Sciences, Kraków) processed and investigated the palynological samples while Katarzyna Narkiewicz M. Sc. (PGI) processed the conodont samples. The figures were drawn by Jan Turczynowicz and Monika Piotrowska, and the photographs were taken by Janina Modrzejewska (all from PGI, Warszawa).

MATERIALS AND METHODS

Present investigations involved description of ca. 130 m of core. The depths of cored intervals have been corrected to the depths shown by the numerical log intepretation, i.e. the ULTRA log (Fig. 2). The latter log enabled fairly precise lithological interpretation of the non-cored intervals although, obviously, details of e.g. sedimentary texture and fossil content have been interpolated between cored intervals.

Petrographic study was based on 31 thin sections stained with the alizarine red-S and supplemented by 7 polished sections. The above materials have been partly illustrated on Plates I–IV. Sedimentological observations and interpretations have been accomplished within the conceptual framework of several published studies of general nature (i.a. J. L. Wilson, 1975; C. W. Byers, 1977; P. A. Scholle *et al.*, 1983; R. G. Walker, N. P. James, 1992). For comparative purposes and for the interpretation of the Devonian sedimentary environments mostly papers on the Devonian carbonate sedimentation in Western Canada have been used (F. A. Stoakes, 1980; J. Wendte *et al.*, 1992).

For biostratigraphic purposes 19 one-kilogram conodont samples and 8 palynological samples have been collected and processed. In the former case, the Middle and Upper Devonian carbonates of relatively open-marine origin have been sampled whereas in the latter — clayey and marly deposits of both lowermost and uppermost part of the studied section.

The negative results of the conodont sample-processing probably reflect a very shallow-water nature of the investigated Devonian deposits. Absence of conodonts is

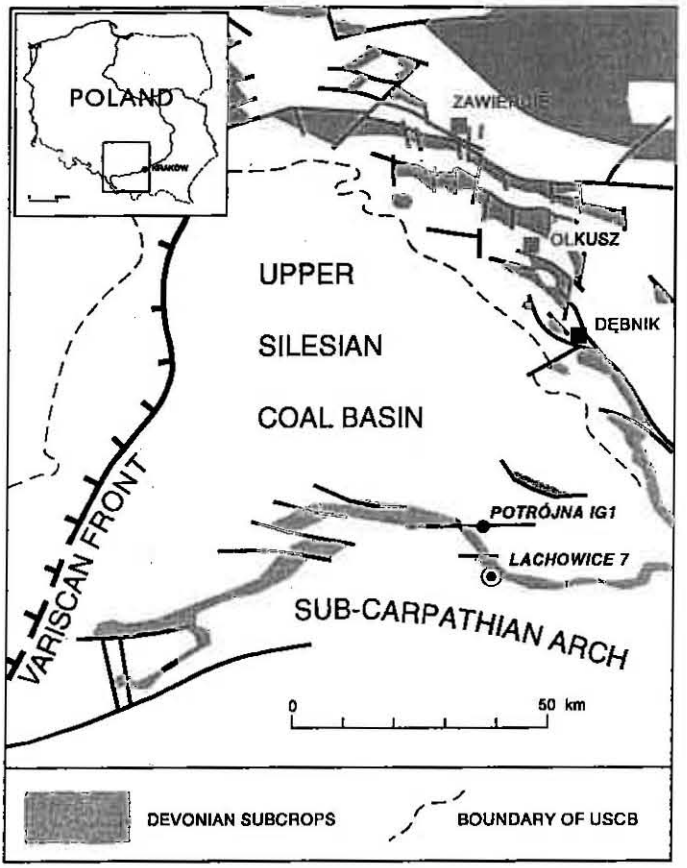
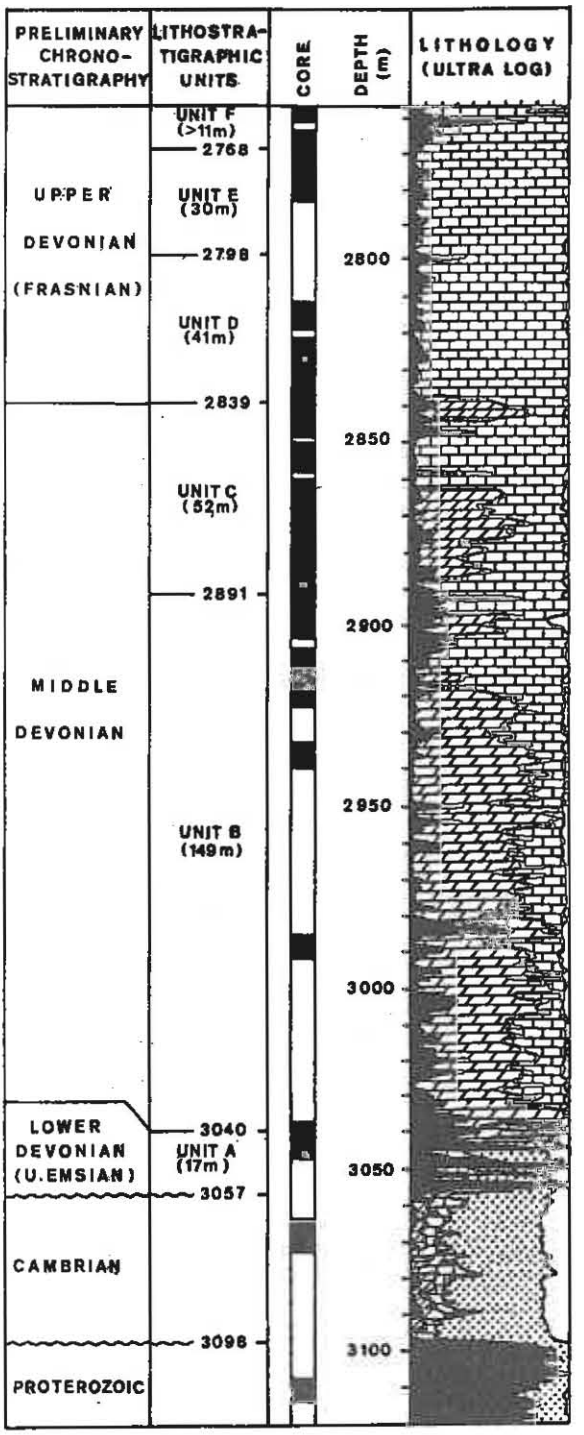


Fig. 1. Location of the studied Lachowice 7 well against the subsurface (sub-Permian) geology of the Silesian-Cracow area; also shown is the location of other sections discussed in the text; Variscan front corresponds approximately to the western limit of the epicontinental Devonian development, with strongly deformed and probably deeper basinal deposits to the west (based on the map by W. Pożaryski and Z. Dembowski, 1984)

Położenie otworu wiertniczego Lachowice 7 na tle geologii wgłębnej obszaru śląsko-krakowskiego oraz innych profili omawianych w tekście; front waryscyjski (Variscan front) odpowiada mniej więcej zachodniemu zasięgowi epikontynentalnych osadów dewońskich, z silnie zdeformowanymi i, przypuszczalnie, głębokowodnymi utworami występującymi dalej ku zachodowi (na podstawie mapy W. Pożaryskiego i Z. Dembowskiego, 1984)

Szrafurą zaznaczono podpowierzchniowe wychodnie dewonu, a linią przerywaną zasięg GZW

particularly significant in view of their relative abundance in the Devonian of the Dębnik area to the north (M. Narkiewicz, G. Racki, 1984).


PRELIMINARY CHRONO-STRATIGRAPHY
LITHOSTRA-TIGRAPHIC UNITS
CORE
DEPTH (m)
LITHOLOGY (ULTRA LOG)
UNIT F (>11m)
2768
UPPER DEVONIAN (FRASNIAN)
UNIT E (30m)
2798
UNIT D (41m)
2839
UNIT C (52m)
2891
MIDDLE DEVONIAN
UNIT B (149m)
LOWER DEVONIAN (U.EMSIAN)
3040
UNIT A (17m)
3057
CAMBRIAN
3098
PROTEROZOIC
2800
2850
2900
2950
3000
3050
3100

LITHOSTRATIGRAPHIC UNITS AND THEIR DEPOSITIONAL SETTING

No lithostratigraphic subdivision of the sub-Carpathian Devonian has been defined as yet. Only very generalized subdivision into the clastic and carbonate complexes has been adopted by various authors. The carbonate complex is being subdivided into the Middle to Upper Devonian stages basing on different criteria, commonly lithological ones. For example, A. Ślączka (1985) described in the nearby Potrójna IG 1 well (Fig. 1) presumably a complete Middle to Upper Devonian interval, distinguishing Eifelian through Famennian stages.

The Devonian interval in the Lachowice 7 well section has been here subdivided into six lithostratigraphic units labelled with the letters A through F in ascending order. The criteria used involved sedimentary characteristics clearly recognizable in cores. Neglected were the secondary attributes related to late diagenetic and tectonic history of the Devonian rocks, particularly to their late dolomitization, fracturing and mineralization.

Most of the lithostratigraphic boundaries could be directly observed in cores (A/B, B/C, C/D, E/F), others, however, were defined according to the wireline log interpretation (base A, D/E). Neither cores nor the ULTRA log cover the uppermost part of the Devonian sequence with thickness up to 17 m (not shown on the Figure 2). Thus, the top of the uppermost unit F has not been investigated. Probably it represents the erosional surface which runs at the base of the Miocene at depth of 2740 m (data of the Exploration and Drilling Companies — Kraków).

The Devonian deposits are underlain by a sandstone unit, 41 m thick, ascribed here to the Cambrian basing on comparisons with the Potrójna IG 1 section (A. Ślączka, 1985). Cored interval, 9 m long, represents light beige quartz sandstones to conglomerates. Cross stratification is common, as are the pebble-sized fragments of light-coloured claystones, mostly flat and arranged parallel to lamination. Interparticle porosity is generally fairly high, particularly so in the coarser grained deposits (Fig. 2). Few horizons with the Scolithos burrows were also observed. The sandstone complex overlies grey to mottled weakly metamorphosed shales and mudstones. Analogous metaargillites were described from the lowermost part of the nearby Potrójna IG 1 section, where they were ascribed to the Proterozoic (A. Ślączka, 1985).

UNIT A — SILICICLASTIC DEPOSITS

Definition. Unit A corresponds to the clastic or terrigenous complex described by various authors in the lowermost part of the Devonian below the Carpathian thrust sheets,

Fig. 2. Stratigraphy of the Devonian in the Lachowice 7 well section; position of cores is corrected according to the interpreted wireline log (ULTRA log); percentage of lithological/mineralogical components is shown with the following patterns: solid black — clay/shale, dotted — sandstone, normal brick — limestone, inclined brick — dolomite , blank (right side of the column) — porosity

Stratygrafia dewonu w profilu otworu wiertniczego Lachowice 7; położenie odcinków rdzeniowanych skorygowano po uwzględnieniu interpretacji karotażowych (log ULTRA); udział składników litologicznych i mineralnych przedstawiono za pomocą szrafury: czarna — ił/łupek, kropkowana — piaskowiec, prosta cegiełkowa — wapień, pochylona cegiełkowa — dolomit, pusta (prawa część profilu graficznego) — porowatość

and traditionally ascribed to the Lower Devonian (i.a. K. Konior, 1966; A. Ślączka, 1985). The unit A presumably represents a counterpart of the "upper unit" distinguished by K. Konior (1966, 1969; see also K. Konior, E. Turnau, 1973) within the "Lower Devonian" of the Bielsko–Andrychów area. The "upper unit" is defined by the cited authors as poorly sorted sandstones, conglomerates and mudstones, locally with Psilophyton flora, and with thickness ranging from 15 to 127 m.

Lower boundary was defined basing on the ULTRA log at depth 3057 m, at the top of uniformly developed sandstone unit. Total thickness is 17 m.

Description. Core observations refer to the uppermost part of the unit (Fig. 2). Characteristic feature of the described deposits is a co-occurrence of three lithological types: (1) quartz gravelstones or conglomerates with poorly sorted and weakly rounded quartz pebbles with diameters up to 2 cm, (2) light beige quartz sandstones with homogeneous texture, and (3) dark green claystones and mudstones with a variable admixture of quartz pebbles, and displaying laminated or homogeneous texture. In the latter lithology also rare bioturbation and pyrite concretions occur. Wireline log interpretation indicates a possibility of distinguishing four to five fining-upward cycles, embracing the above listed lithologies.

Depositional setting. Lack of any indicators of marine environment suggests overall continental depositional setting, most probably alluvial fan facies proximal to area of denudation.

UNIT B — CORAL-STROMATOPOROID LIMESTONES AND DOLOMICRITES

Definition. Unit B is characterized by a co-occurrence of limestones and crypto- to microcrystalline dolostones. In addition, abundant finely to medium crystalline dolostones irregularly replace primary calcareous lithology.

Description. Observations reported below may not be fully representative for the entire thickness of the unit due to poor coring and unsatisfactory core recovery.

In the lowermost part, within the interval of less than 3 m, there occur subordinate sandstone-mudstone intercalations while carbonate content rapidly increases upwards. Carbonates are here developed as crypto- to microcrystalline dolostones displaying yellowish, light beige to grey and dark grey colours. Sand and clay admixture is of variable importance. Several intercalations of green-greyish dolomitic marls and even black dolomitic mudstones were observed, the latter with relics of unidentified ramose skeletons. In general, the above rocks display weakly defined sedimentary textures, mostly homogeneous, with rare fenestrae, intraclastic horizons and flaser-like clay seams.

Wireline log interpretation indicates the occurrence of a continuous dolomitic complex embracing the lower 120 m of the unit (Fig. 2). Dolostones are represented by both micro- to cryptocrystalline rocks and dolosparites replacing primary limestones. Also, several horizons of a dolomitic intraformational breccia or conglomerate have been noted within the described unit (Pl. I, Fig. 4). It is impossible, however, to reconstruct the distribution of the above dolomite types basing on the wireline log alone.

Calcareous deposits, predominant in the topmost 30 m of the section, consist of light-coloured mudstones to packstones. Larger organic skeletons form variable although generally important component, mostly including domal, bulbous and ramose stromatoporoids, branching tabulate corals, and, subordinately, crinoids, brachiopods and gastropods.

In several cases skeletal accumulations display attributes of stromatoporoid biolithites. The clayey admixture is negligible — it occurs as few wavy residual seams. Several levels with fenestral structures have been found, at least partly being related to burrowing processes.

The microscope study revealed that dolomicrites display neomorphism ultimately leading to development of dolomicrospar. An accessory component is formed of poorly sorted and rounded quartz sand. Few bioclasts are represented by calcispheres and ostracods while uncommon intraclasts are built of spongy, cryptalgal micrite.

Among limestones the occurrence of pelbiomicrites and biomicrites has been found, with tiny tube-like algae, ostracods and calcispheres. Irregularly occurring grainstone patches owe their texture most probably to organic reworking of an original packstone-type sediment (Pl. I, Fig. 3).

Depositional setting. Micro- to cryptocrystalline dolostones are here interpreted as peritidal deposits that formed while still residing in their sedimentary environment, in the presence of a seawater concentrated by evaporation. The primary calcareous deposits, represented mainly by biolithites and skeletal wackestones, may be attributed to shallow subtidal or lower intertidal zone. The co-occurrence of the two main lithological types in the section may suggest the existence of peritidal shallowing-upward cycles within the nearshore proximal part of an attached carbonate platform.

UNIT C — AMPHIPORA LIMESTONES

Definition. The important diagnostic feature of the unit is its primary calcareous development and relatively insignificant clay admixture, in contrast to the lower unit. Ramose stromatoporoids markedly predominate among the skeletal constituents. About half of the section is formed of crystalline dolostones with numerous relics of primary limestone textures (Pl. II, Fig. 5). Common are irregular contacts between both lithologies, commonly cross-cutting individual beds. It is here interpreted that the dolosparites were formed due to late (mesogenetic) dolomitization of primary calcareous deposits.

Lower boundary was placed at the top of the uppermost dolomicrite intercalation, at depth 2891 m. Total thickness is 52 m.

Description. Unaltered parts of the section are represented by light-coloured wackestones to packstones, with subordinate grainstones. Texture is homogeneous, in rare cases laminated. Among macroscopically discernible skeletal components ramose stromatoporoids predominate, with a lesser proportion of domal or bulbous stromatoporoids.

Thin-section study revealed biopelmicritic character of the limestones with irregular sparitic areas most probably of bioturbational origin. Microscopic skeletal remains are represented by algal tubes, calcispheres, ostracods and problematic unilocular foraminifers.

Depositional setting. Deposition took place in the environment similar to that of the unit B. Lack of eogenetic dolostones or other evidence of increased salinity suggests deposition more remote from the coastal areas, probably in more centrally located areas of a carbonate platform. Poor skeletal assemblage is typical for lagoonal/intertidal restricted environments of Devonian carbonate platforms. It suggests a certain degree of isolation from the normal open marine environment, in areas remote from a platform margin.

UNIT D — WAVY-NODULAR LIMESTONES

Definition. The most characteristic feature of the unit D is the common presence of clayey residual seams. They are wavy but generally parallel to bedding, and with their increased thickness and density they may form fabrics transitional to a nodular structure (Pl. II, Figs. 6–8). It should be stressed, however, that typical nodular limestones, with marked contrast between nodules and darker marly matrix, are quantitatively insignificant in the unit D. Crystalline dolostones replace only the lowermost 2 m of the unit.

Lower boundary is defined by the lowermost occurrence of numerous wavy clayey seams within the partly dolomitized limestones. Total thickness of the unit D is 41 m.

Description. Typical for the unit, moderate enrichment in the terrigenous clay component, is reflected in wavy-nodular structure of beige-grey to beige limestones (Pl. II, Fig. 6). In contrast to typical nodular limestones they contain considerable proportion of grains including skeletal components, and may be generally described as skeletal packstones and even grainstones in places. Abundant skeletal constituents are mostly represented by ramose stromatoporoids, less common are small bulbous forms, ramose and domal tabulates, brachiopods, gastropods and crinoids (Pl. II, Figs. 7, 8). Part of the skeletons displays evidence of slight redeposition, namely overturning, disarticulation and breakage. In general, unit D is exceptional among the described units in terms of its high biotic abundance and diversity.

Bioturbation is typical for the described unit, evidenced i.a. by horizontal tubular burrows. Present are also oncoids and micritic intraclasts with lighter rims probably due to synsedimentary oxidation.

Microscope investigations revealed that the packstones are represented by biopelmicrites with calcispheres, unilocular foraminifers, sparitic (algal?) tubes, ostracods and dissolved fragments of mollusc shells. Characteristic are patches of a "loose fabric" formed of grainstones, as well as chaotic orientation of bioclasts, both evidencing intense sediment-reworking by burrowing organisms.

Grainstones may be described as intrabiosparites with intraclasts up to 1 cm in diameter, built of micrites, fenestral pelmicrites and biomicrites. Skeletal detritus is composed, in addition to the above named fossil groups, also of Amphipora fragments, echinoid spines and red algal skeletons.

Depositional setting. Rich organic assemblage includes typical Devonian normal marine taxa, which points to exceptionally open marine character of the unit D in comparison with the other described units. Generally light colour, abundance of intraclasts and other grains, indicate rather agitated depositional environment. On the other hand, however, accumulation of considerable clay admixture suggests at least intermittently calm hydrodynamic regime. Taking the above interpretations into account (compare also unit C), it can be assumed that the boundary between units C and D represents deepening of a depositional environment from several metres as interpreted for the unit C to few tens of metres (unit D). The latter deeper environment corresponds to a middle or upper carbonate ramp or to upper slope of a platform. Regional correlations (Tab. 1, see below) suggest the former possibility as being more plausible.

Table 1

Correlation of the Middle and Upper Devonian lithostratigraphic subdivisions in the Dębnik area and in the Lachowice 7 well, and comparison of interpreted depositional systems and/or facies

CHRONOSTRATIGRAPHY	DĘBNIK AREA		LACHOWICE 7	
	LITHOSTRATIGRAPHY (M.Narkiewicz, G.Racki, 1984)	DEPOSITIONAL SYSTEMS AND / OR FACIES	LITHOSTRATIGRAPHY (this paper)	DEPOSITIONAL SYSTEMS AND / OR FACIES
FAMENNIAN	GRAINED AND MICRITIC LIMESTONE (THICKNESS UKNOWN)	PROGRADING PERITIDAL PLATFORM	EROSIONAL GAP	
	PLATY LIMESTONE (>70 m)	SHELF BASIN (aerobic - dysaerobic)		
FRASNIAN	GRAINED LIMESTONE (>34 m)	MIDDLE RAMP (shallowing upward)	UNIT F (>34 m)	RESTRICTED SHALLOW SUBTIDAL PLATFORM
			UNIT E (30 m)	PROXIMAL RAMP
	NODULAR LIMESTONE (30 m)	TRANSITIONAL FROM LOWER RAMP TO SHELF BASIN	UNIT D (41 m)	MIDDLE-UPPER RAMP
GIVETIAN	DĘBNIK LIMESTONE (35 m)	SHALLOW SUBTIDAL PLATFORM (OUTER?) (partly dysaerobic)	UNIT C (52 m)	MIDDLE PLATFORM
EIFELIAN ?	ZBRZA DOLOSTONE (>260 m)	PERITIDAL TO RESTRICTED SUBTIDAL PLATFORM	UNIT B (149 m)	PROXIMAL PLATFORM (peritidal cycles)

Note that isochronous units represent shallower or more proximal depositional settings southwards, i.e. towards the Sub-Carpathian Arch

UNIT E — GRAINED LIMESTONES

Definition. The diagnostic features include purely calcareous development, distinctly grained appearance and insignificant occurrence of macroscopic skeletal components.

Lower boundary has been identified in the ULTRA log at the top of a prominent clayey intercalation, at depth 2798 m (Fig. 2). Higher in the section, similar intercalations appear only in the bottom part of the unit F. Total thickness of the unit E is 30 m.

Description. The light beige-grey limestones are characterized by a lack of any significant clay admixture, with presence of merely stylolitic sutures and subordinate thin marly residual seams. Packstones and grainstones predominate over mudstones and wackestones. Among larger grains micritic intraclasts can be commonly identified, in one case forming a distinct intraformational conglomerate level. Within the grained limestones there occur horizons with abundant macroscopic skeletons, in particular those of ramose stromatoporoids, less commonly domal stromatoporoids, ramose tabulates and brachiopods. Also found were algal structures represented by oncoids and subordinate cryptalgal lamination.

Thin sections reveal variable microfacies types: from biopelmicrites and intrabiomicrites to (pel)intrabiosparites and Amphipora biointrasparites (Pl. III, Figs. 9, 10). In

intrabiomicrites common are patches of sparite interpreted here as formed by burrowing activity. Skeletal assemblage is fairly uniform throughout the above types and embraces: fragments of ramose stromatoporoids, algal tubes, unilocular foraminifers, calcispheres and ostracods. Among non-skeletal grains grapestones have been found. Moreover, Amphipora skeletons commonly display micritization.

Depositional setting. In general, the unit E represents a very shallow marine depositional environment as evidenced by large proportion of reworked grains, light colours and algal structures. At the same time, however, there is a clear open marine influence reflected in a diverse organic assemblage. The described unit records superposition of several episodes of more isolated environments (Amphipora-calcisphere-ostracod assemblage with bahamites) and more open marine ones (tabulate corals and brachiopods). The former facies were more important quantitatively. The base of the unit records a phase of a distinct shallowing: the depositional setting shifts up to a proximal zone of a carbonate ramp environment.

UNIT F — DARK MARLY LIMESTONES AND INTRAFORMATIONAL CONGLOMERATES

Definition. Unit F is characterized by its dark colour, clayey admixture in the form of residual seams and nodular limestone levels, and by characteristic intraclast horizons.

Lower boundary has been placed at the base of an interval with dark grey to black marly limestones with clayey residual seams. The minimum thickness of the unit within the interval available for present observations is 11 m, and it ranges up to 28 m assuming a continuity of the unit up to the sub-Miocene unconformity surface.

Description. Unit F is represented by a short cored interval with rather variable sedimentological characteristics. It includes: (1) almost black mudstones (but with transitions to light pinkish) slightly marly, with clayey seams; (2) intraformational conglomerates composed of poorly sorted and weakly rounded micritic intraclasts with a diameter up to 4 cm, and with a marly micritic matrix (Pl. IV, Fig. 14); (3) nodular mudstones with strongly (tectonically?) deformed nodules and with greenish marly matrix; (4) grained limestones, packstones to grainstones with clayey wavy seams and intraclast horizons. Dark colours predominate, although some intraclasts are built of light micrite, and, in several cases they display lighter (oxidation?) rims.

According to microscope investigations, the intraformational conglomerates consist of densely packed intraclasts with a presence of cryptalgal clasts and an admixture of few quartz sand grains. Matrix is composed of intra(pel)sparite with calcispheres and Amphipora fragments. The microfacies spectrum embraces: (1) pel(intra)biomicrite with transitions to sparite, and with fenestral structures, ostracods, calcispheres, unilocular foraminifers and algal tubes (Pl. IV, Fig. 13); (2) intrasparite to pelsparite with calcispheres and intraclasts of (at least partly) algal origin (Pl. III, Figs. 11, 12); (3) biopelmicrite with fenestrae and bioclasts as in type (1) but with additional brachiopod and echinoid fragments (Pl. IV, Fig. 15).

Depositional setting. Poor organic assemblage is typical for the Devonian shallow marine environments somewhat isolated from the influence of an open sea. The isolation is also indicated by dark colours suggesting oxygen deficiency in near-bottom water, and thus a dysaerobic environment with some infaunal traces still present. The isolated areas were

quite shallow-water as evidenced by intermittently increased water turbulence, oxidation halos, and a lack of typical pelagic organisms, including conodonts. Thus, we are dealing with a restricted shallow subtidal platform environment rather than with a deeper shelf-basin setting.

CHRONOSTRATIGRAPHY AND TENTATIVE REGIONAL CORRELATION

Biostratigraphic investigations of palynomorphs and conodonts in the studied section appeared unsuccessful and thus the following regional correlation of the Devonian will be based entirely on the lithostratigraphic and facies criteria.

Presumable equivalent of the unit A in the area of Bielsko Biała, Andrychów and Wysoka towns is generally named "the upper unit of the Lower Devonian" (see above) and has been dated by E. Turnau (1974) as probable late Emsian.

Comparisons between the Lachowice 7 well and the Potrójna IG 1 well located ca. 10 km to the north (Fig. 1) appear difficult. The latter section has not been subdivided into lithostratigraphic units (*cf.* A. Ślączka, 1985), moreover poor coring and highly generalized lithological descriptions preclude direct comparisons with the units described in this report. A comparison of the total corrected thickness of the Devonian carbonates in the Potrójna IG 1 section (457.5 m) and in the Lachowice 7 well (cored interval — 283 m) indicates that in the latter well upper part of the Devonian sequence is lacking. In view of proximity of both wells one can assume no considerable thickness variations of the Devonian between both sections. Given the above assumption, it seems conceivable that the uppermost part of the Devonian carbonates in the Lachowice 7 section corresponds to a middle portion of the deposits ascribed by A. Ślączka (1985, p. 49–51) to non-subdivided Frasnian-Famennian (Potrójna IG 1 well, depth ca. 3000 m). The latter deposits have no direct biostratigraphic dating but they overlie limestones ascribed to the Upper Devonian (Frasnian) based on "*...fauna determined by M. Pajchlowa from the depth 3104–3162 m and on microfaunal investigations*". Above the depth 3000 m, starting from 2960 m and up to the top of the Devonian in the Potrójna IG 1 section, there occur characteristic mudstone-claystone and sandstone intercalations. Comparable deposits have not been found neither in cores nor in the ULTRA log interpretation of the Lachowice 7 section. This would support the interpretation of secondary (erosional?) removal of the equivalents of the upper part of the Potrójna IG 1 Devonian sequence in the area of Lachowice.

The Dębnik area, located ca. 50 km to the north of the Lachowice 7 well (Fig. 1), has a detailed litho- and biostratigraphic documentation of the Devonian carbonate sequence (M. Narkiewicz, G. Racki, 1984). Even a superficial comparison of this sequence with the Lachowice 7 section enables a conclusion that in the latter section the Devonian carbonates are generally represented by more shallow marine facies, commonly equivalents of proximal or central areas of an attached carbonate platform, or nearshore portions of a carbonate ramp (Tab. 1). The deposits in question are lacking thick marly units representing the shelf-basinal setting interpreted for some of the Dębnik depositional units, and, particularly, for the Upper Devonian in the Olkusz–Zawiercie area more to the north. This is consistent with the palaeogeographic model of the southern part of the Middle to Late Devonian epicontinental basin in Poland (M. Narkiewicz, G. Racki, 1985, 1987). The above model

assumes overall shallowing of depositional environments southwards towards the Sub-Carpathian Arch, accompanied by the thickness-reduction of the Devonian carbonate sequence.

The Lachowice 7 section lacks any of the lithostratigraphic units described earlier in the Dębnik area (Tab. 1). The unit B shows a general similarity to the Zbrza Dolostone (*cf.* M. Narkiewicz, G. Racki, 1984), it differs, however, from the latter in being lighter-coloured. In turn, the unit C, although similar to the Dębnik Limestone in showing generally biostromal development and comparable faunal assemblage, differs from the latter unit in being lighter and displaying larger percentage of grains at the expense of carbonate mud. The above disparities are generally consistent with the assumed regional facies patterns in the north-south direction.

The key role for the correlation of both the sequences seems to play the unit D, i.e. the wavy-nodular limestones. With respect to lithology this unit appears similar to the Nodular Limestone of the Dębnik section (Tab. 1). It differs in having less clayey admixture and, consequently, less distinct nodular structure. Also, it displays lighter colours, considerable admixture of grains, including skeletal components, and, in particular, algal material. The above differences can be explained in terms of a conceptual framework of a carbonate ramp shallowing to the south (Tab. 1). Apart from the lithological similarities, another important premise for the correlation of both the discussed units is their position in the respective Devonian successions. In both the cases the units in question represent the episode of a clear and distinct deepening of depositional environment after the prolonged development of a very shallow-water biostromal carbonate platform. In the Devonian Lachowice 7 section the unit D represents the maximum palaeowater depth. The overlying units have been interpreted as deposited in shallower marine facies.

Taking into account the above arguments, the interpretation has been adopted here that the unit D corresponds to the basal Frasnian transgression recorded in numerous sequences of the Devonian basin in Poland and elsewhere. In the Dębnik area this event is represented by the base of the Nodular Limestone belonging to the conodont *falsiovalis* to *transitans* Zone interval (M. Narkiewicz, G. Racki, 1984). The above interpretation implies that the units E and F correlate with the Grained Limestone in the Dębnik area (Tab. 1). The Lachowice 7 section lacks evidence of a distinct deepening of a sedimentary environment which would correspond to the late Frasnian transgressive pulse recorded in the Dębnik area as the Platy Limestone unit (Tab. 1). It is consistent with the earlier conclusion on the possible lack of the upper part of the Devonian sequence in the Lachowice area, based on the comparison with the Potrójna IG 1 well section.

SUMMARY AND CONCLUSIONS

Present investigations of core material along with the wireline log interpretations of the Devonian interval in the Lachowice 7 deep well provided a firm basis for establishment of the lithostratigraphic subdivision into six informal units A to F of a formation or member rank (Fig. 2). The subdivision may serve as a working stratigraphic scheme in correlations of the Devonian in the Carpathian substrate. It does not include, however, the uppermost part of the Devonian succession whereas its lower part, the unit B in particular, has a poor

core control. Future studies will eventually lead to a more complete and refined scheme, and will provide more comprehensive description of distinguished units.

Application of biostratigraphic methods to the studied material appeared unsuccessful in view of lack of conodonts and palynomorphs. In the case of the unit A (siliciclastic deposits) a more precise dating can be possibly achieved by future acritarch investigations (E. Turnau, unpublished report). Dating of the carbonate complex is more problematic at present as it can be based solely on less diagnostic macrofaunal determinations. The above methodological difficulties imply a relative importance of lithostratigraphic and sequence- or event-stratigraphic correlations in future regional studies.

Basing on the lithostratigraphic and facies correlations a working hypothesis is put forward here that the unit D represents the basal Frasnian transgression, and thus the base of the Upper Devonian sequence. This allows for a tentative establishment of the Middle-Upper Devonian boundary in the Lachowice 7 well at depth 2839 m. The thickness comparisons with the nearby Potrójna IG 1 well and correlations with the Dębnik area indicate that the upper part of the Upper Devonian (uppermost Frasnian and Famennian) is missing from the studied section due to post-Early Carboniferous and pre-Miocene erosion.

Present investigations allowed for the interpretation of depositional environments of successive Devonian units. In general, the Lower Devonian deposits, of probable late Emsian age, represent proximal alluvial fan facies whereas Middle to Upper Devonian carbonate complex was deposited in proximal or central parts of the carbonate attached platform or ramp system (Tab. 1). Significantly, the latter complex is lacking dark marly anaerobic to dysaerobic deposits typical of the Devonian shelf-basin in southern Poland (*cf.* M. Narkiewicz, G. Racki, 1985). The results of the present study confirm and further substantiate earlier concepts of wedging out of the Devonian deposits southwards towards the Sub-Carpathian Arch parallelled by shallowing of respective depositional environments (M. Narkiewicz, 1978; M. Narkiewicz, G. Racki, 1987).

Regional patterns of depositional thickness changes as well as gradients of palaeoenvironmental transitions in proximity of the Sub-Carpathian Arch confirm its palaeogeographic importance as a stable elevated area during the Devonian. At the same time, however, the present correlations suggest that the presently observed limit of the Devonian subcrops (Fig. 1) is considerably shifted northwards due to post-depositional erosional events. The Devonian basin most probably extended at least few tens of kilometres southwards of the present southern subcrop limit shown on Figure 1.

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Received: 22.11.1995

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STRATYGRAFIA I ŚRODOWISKA SEDYMENTACJI DEWONU W POBLIŻU WYNIESIENIA PODKARPACKIEGO: OTWÓR LACHOWICE 7

Streszczenie

Badania materiału rdzeniowego i interpretacje karotażowe utworów dewonu, przewierconych w otworze Lachowice 7 koło Suchej Beskidzkiej (fig. 1), umożliwiły zestawienie podziału litostratygraficznego, obejmującego 6 nieformalnych jednostek (A–F) o randze formacji lub ogniw (fig. 2; por. ilustracje na tabl. I–IV). Schemat nie obejmuje wyższej części sekwencji dewońskiej, a dolny jej fragment (zwłaszcza jednostka B) ma słabą dokumentację rdzeniową. Korelacja litostratygraficzna i facjalna umożliwia postawienie roboczej hipotezy, że jednostka D reprezentuje podstawową transgresję frańską, a zatem spąg dewonu górnego. Pozwala to na wstępne wyznaczenie granicy między dewonem środkowym a górnym na głębokości 2839 m. Porównania miąższościowe z profilem otworu Potrójna IG 1 i korelacje z dewonem rejonu Krzeszowic wskazują na brak w badanym profilu wyższej części dewonu górnego, obejmującej cały famen i przypuszczalnie najwyższą część franu.

Analiza sedymentologiczna utworów dewońskich pozwoliła na interpretację zmiennego w czasie środowiska depozycji (tab. 1). Utwory dolnodewońskie jednostki A (przypuszczalnie wyższy ems) reprezentują facje proksymalnego stożka aluwialnego. Utwory dewonu środkowego i górnego osadzały się w proksymalnej lub centralnej części węglanowej platformy przybrzeżnej lub rampy, natomiast nie wykazują obecności ciemnych, marglistych

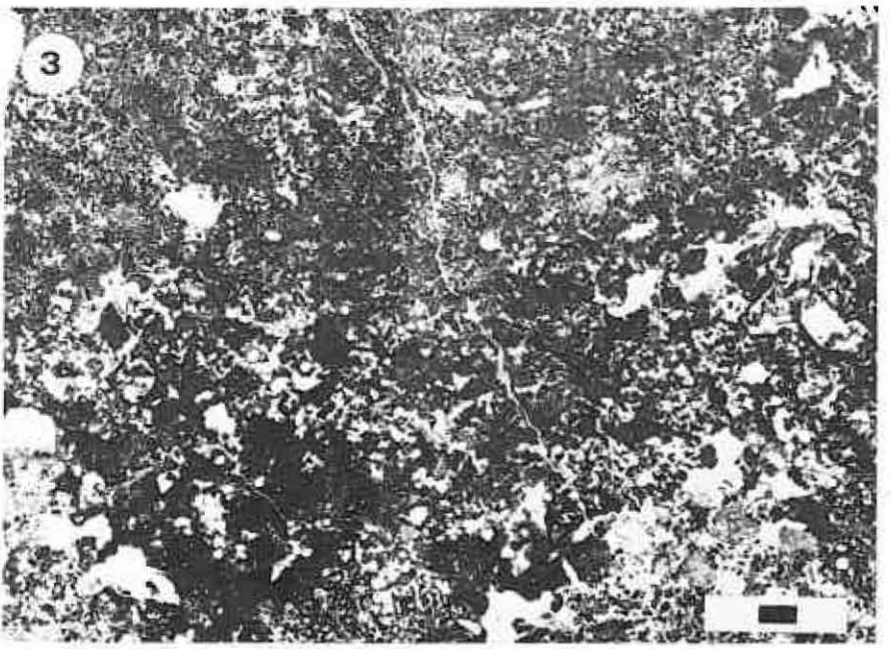
utworów typowych dla dewońskiego basenu szelfowego (por. M. Narkiewicz, G. Racki, 1985). Wyniki badań potwierdzają wcześniejsze hipotezy o spłycaniu się i wyklinowaniu utworów dewońskich ku południowi, w stronę wyniesienia podkarpackiego („lądu prakarpackiego" we wcześniejszej literaturze).

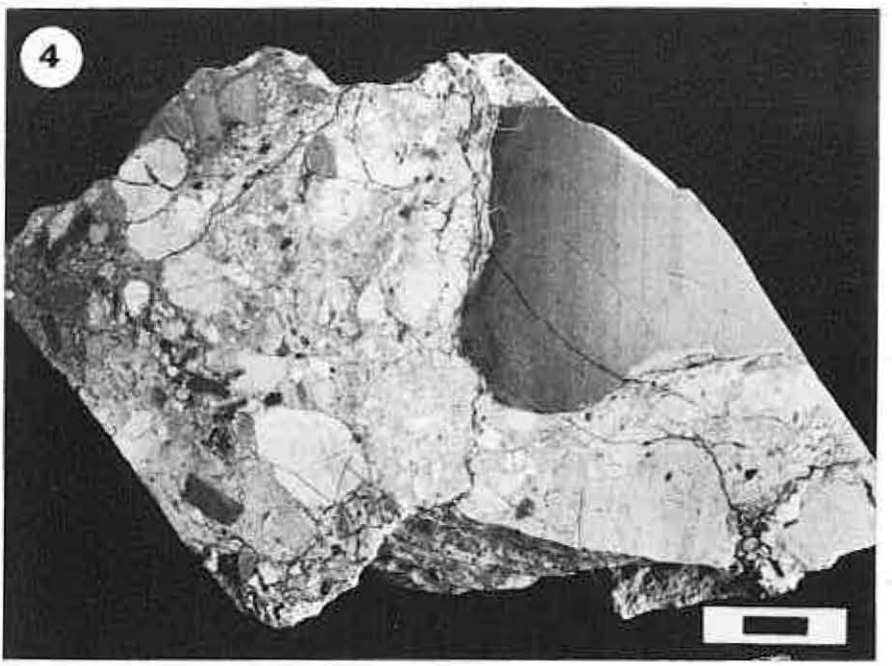
Gradienty tych zmian są jednak na tyle niewielkie, że sugerują możliwość znacznego przesunięcia na południe interpretowanego maksymalnego zasięgu zbiornika dewońskiego. Linię pierwotnego brzegu basenu, zwłaszcza we franie, należałoby poprowadzić jeszcze o kilkadziesiąt kilometrów na południe od zaznaczonego na fig. 1 pasa podpowierzchniowych wychodni dewonu.

PLATE I

Fig. 3. Pelbiomicrite irregularly grading into pelbiosparite, and with irregular fenestrae; unit B, thin section, depth 2905.2 m
Pelbiomikryt z nieregularnymi przejściami w pelbiosparyt i nieregularnymi fenestrami; jednostka B, szlif, głęb. 2905,2 m
Fig. 4. Dolomitic conglomerate with poorly sorted dolomicrite clasts and marly matrix; unit B, polished section, depth 2895.7 m
Zlepieniec dolomitowy ze źle wysortowanymi klastami dolomikrytowymi i marglistym tłem; jednostka B, naszlif, głęb. 2895,7 m

All illustrated specimens are from the Lachowice 7 well; length of scale bar is 1 mm for thin section photographs and 1 cm for polished section photographs
Wszystkie zilustrowane okazy pochodzą z otworu wiertniczego Lachowice 7; długość skali odpowiada 1 mm w przypadku szlifów, a 1 cm w przypadku naszlifów





Marek NARKIEWICZ — Devonian stratigraphy and depositional environments in proximity of the Sub-Carpathian Arch: Lachowice 7 well, southern Poland

PLATE II

Fig. 5. Light-coloured Amphipora limestone (upper part of the photograph) irregularly replaced by dark dolosparite (bottom); middle part represents selective replacement of a lime mud matrix; unit C, polished section, depth 2880.9 m

Warstwa jasnego wapienia amfiporowego (góra zdjęcia) nieregularnie zastępowana przez ciemny dolosparyt (dół); w środkowej części zdjęcia widoczna selektywna dolomityzacja mikrytowego tła skalnego; jednostka C, naszlif, głęb. 2880,9 m

Fig. 6. Micritic nodular limestone (mudstone to wackestone) displaying small amounts of marly matrix; unit D, polished section, depth 2823.6 m

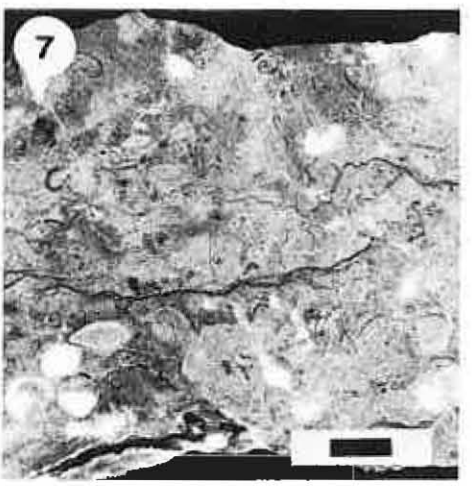
Mikrytowy wapień gruzłowy z niewielkim udziałem marglistego tła skalnego; jednostka D, naszlif, głęb. 2823,6 m

Fig. 7. Strongly bioturbated lime wackestone with abundant intraclasts, oncoids and organic skeletons, mainly gastropod and brachiopod shells; present are thin residual clayey seams; unit D, polished section, depth 2810.5 m

Silnie zbioturbowany wapień mikrytowo-ziarnowy z licznymi intraklastami, onkoidami i szkieletami organicznymi, głównie ślimaków i ramienionogów; obecne cienkie rezydualne smugi ilaste; jednostka D, naszlif, głęb. 2810,5 m

Fig. 8. Amphipora limestone with a few small bulbous stromatoporoids and crinoid remains; note wavy clayey seams between skeletons; unit D, polished section, depth 2829.1 m

Wapień amfiporowy z pojedynczymi, małymi stromatoporami masywnymi i trochitami; faliste smugi ilaste między szkieletami; jednostka D, naszlif, głęb. 2829,1 m



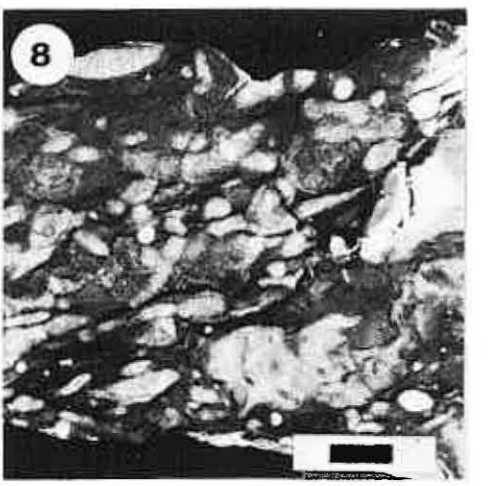


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PLATE III

Fig. 9. Intrabiosparite with irregular gradations to intrabiomicrite; organic skeletons include strongly abraded Amphipora branches, tiny sparitic algal tubes, unilocular foraminifers, calcispheres and ostracods; unit E, thin section, depth 2778.8 m

Intrabiosparyt z nieregularnymi przejściami w intrabiomikryt; wśród szkieletów organicznych obecne silnie zabradowane gałązki amfipor, rurki sparytowe (glonowe), jednokomorowe otwornice, kalcysfery i małżoraczki; jednostka E, szlif, głęb. 2778,8 m

Fig. 10. Contact between the bioturbated intrabiomicrite and poorly sorted pel/intrasparite; unit E, thin section, depth 2777.6 m

Kontakt zbioturbowanego intrabiomikrytu z pel/intrasparytem źle wysortowanym; jednostka E, szlif, głęb. 2777,6 m

Fig. 11. Pel/intrasparite with irregularly distributed micritic matrix and a skeletal admixture; unit F, thin section, depth 2754.7 m

Pel/intrasparyt z nieregularnymi partiami mikrytowymi i domieszką szkieletową; jednostka F, szlif, głęb. 2754,7 m

Fig. 12. Intrapelsparite; unit F, thin section, depth 2760.05 m

Intrapelsparyt; jednostka F, szlif, głęb. 2760,05 m

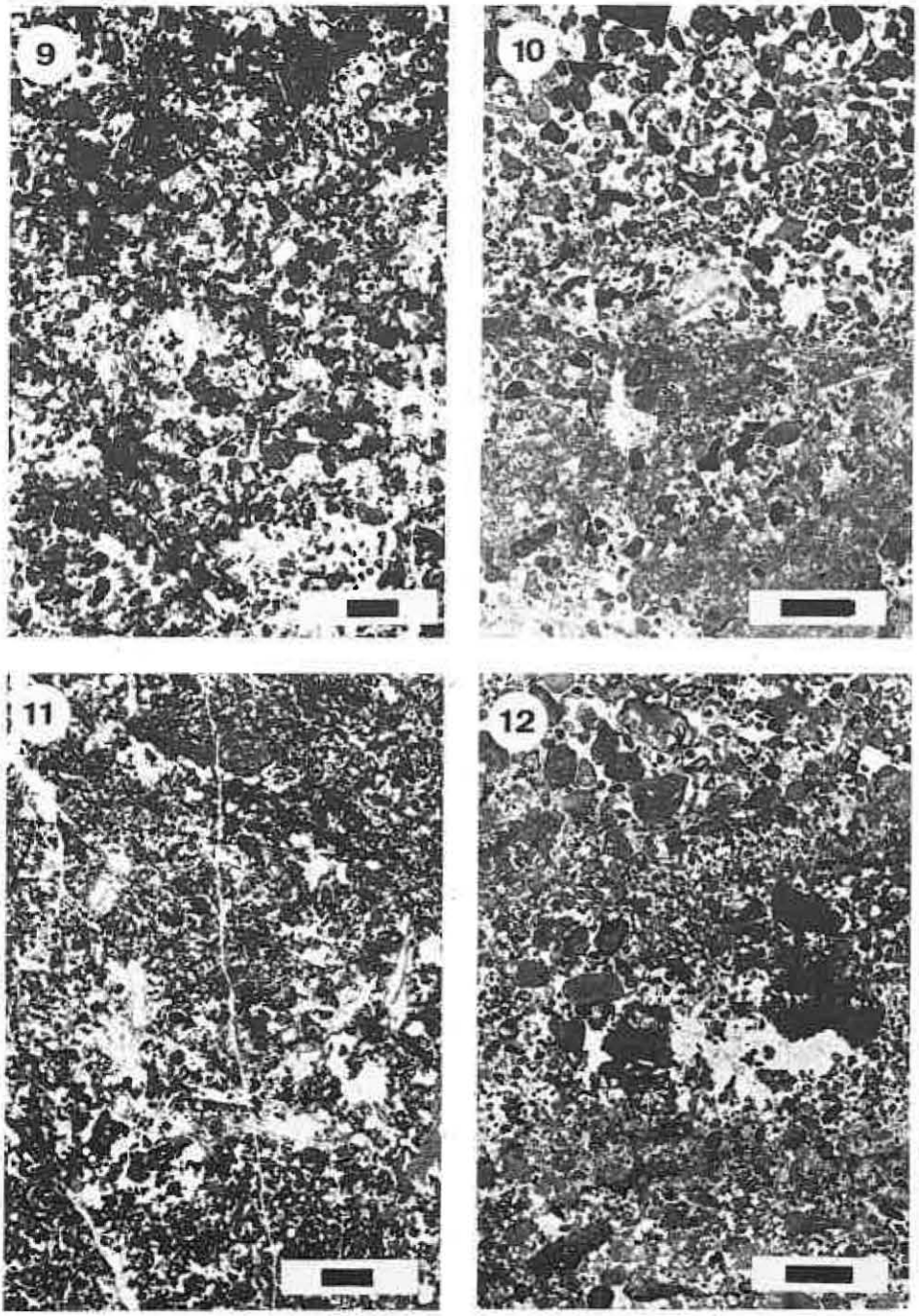

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PLATE IV

Fig. 13. Erosional surface topping skeletal wackestone with small algal remains, ostracods and calcispheres; above — wackestone to packstone with large intraclasts and irregular fenestral fabric; unit F, thin section, depth 2766.95 m

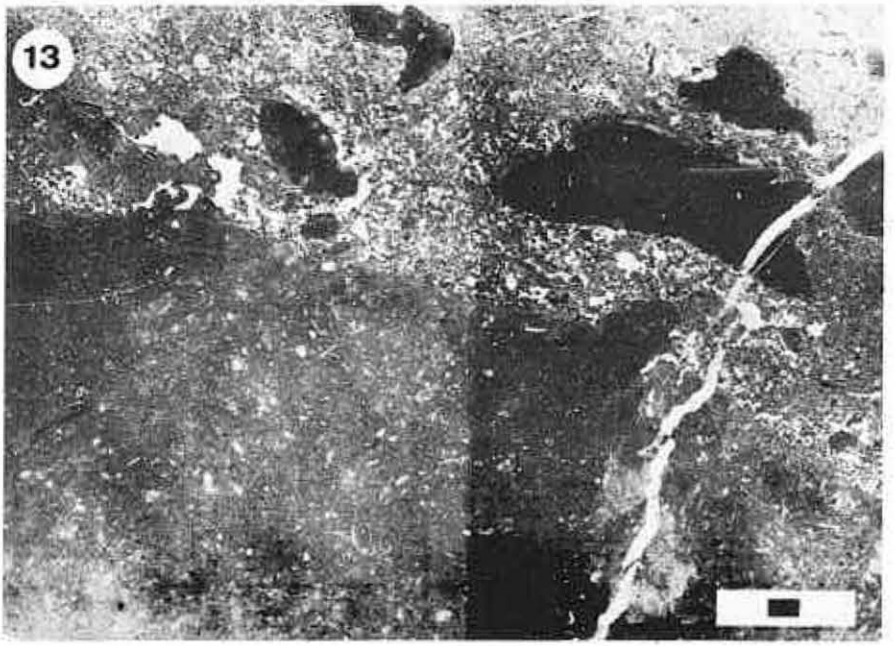
Powierzchnia erozyjna rozwinięta na szkieletowym wapieniu mikrytowo-ziarnowym z drobnymi bioklastami glonowymi, małżoraczkami i kalcysferami; na niej — wapień od mikrytowo-ziarnowego do ziarnowo-mikrytowego, z dużymi intraklastami i nieregularnymi fenestrami w tle; jednostka F, szlif, głęb. 2766,95 m

Fig. 14. Poorly sorted calcarenite-calcirudite with micritic intraclasts; unit F, thin section, depth 2754.05 m

Źle wysortowany kalkarenit-kalcyrudyt z intraklastami mikrytowymi; jednostka F, naszlif, głęb. 2754,05 m

Fig. 15. Biopelmicrite grading irregularly into biopelsparite; fine skeletal material is composed mostly of ostracod remains, calcispheres, algal tubes and unilocular foraminifers; unit F, thin section, depth 2753.05 m

Biopelmikryt nieregularnie przechodzący w biopelsparyt; drobny materiał szkieletowy składa się głównie ze szczątków małżoraczków, kalcysfer, rurek glonowych i otwornic jednokomorowych; jednostka F, szlif, głęb. 2753,05 m



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