KARIN RITZMANN
Freiberg University of Mining and Technology,
Institute of Geology, *Germany*

MARINE / CONTINENTAL FACIES PATTERNS, SEQUENCE STRATIGRAPHY AND A GOCAD-3D-MODELLING OF THE CARBONIFEROUS / PERMIAN-BOUNDARY OF THE DONETSK BASIN

Донецкий бассейн является юго-восточной частью внутренней кратогенной рифтовой системы Припять-Днепр-Донецк, протянувшейся с северо-запада на юго-восток от Беларуси через территорию Украины на расстояние около 1500 км до Восточно-Европейской платформы. На территории Донецкого бассейна профили позднего каменноугольного и пермского периодов характеризуются взаимным переслаиванием океанических и континентальных осадочных пород. Существует возможность установить соответствие неокеанических профилей каменноугольного и пермского периодов Западной Европы с мировой океанической стратиграфической шкалой. Детальное изучение фациальных образцов и восстановление условий осаждения основываются на обширных полевых исследованиях в районе Донецкого бассейна. Было произведено изучение микрофаций и микропалеонтологические исследования 110 образцов известняка. Стратиграфические разрезы верхних каменноугольных и нижних пермских последовательностей Артемовского района были сопоставлены со стратотипным разрезом (скважина № 4199 «Скосырская») Придонецкого бассейна, где преобладают океанические осадочные породы (Alekseeva et al. 1983). Описание 2455 м литостратиграфических профилей (Makarov et al. 1985 a и Aizenverg et al. 1975) и дополнительные фациальные профили 51 скважины (Makarov et al. 1985 b) использовались совместно с данными, полученными авторами, для построения стратиграфической модели последовательности седиментации в Донецком бассейне. Максимальные поверхности затопления тракта трансгрессивных систем представлены угольными пластами. Границы секвенций соответствуют основаниям эрозийных речных каналов. Границы секвенций и максимальные поверхности затопления являются четко выделенными горизонтами на всей изучаемой территории. Результаты фациального анализа и стратиграфической модели последовательности седиментации были использованы для построения условной кривой уровня моря для Донецкого бассейна. Выбрана модель осадконакопления (Izart et al. 1998). Она стала основой для сравнения условных кривых уровня моря Донецкого бассейна и Мирового океана, а также для оценки климатических изменений как определяющего фактора колебания уровня моря. Объемная модель GOCAD-3D разработана для трехмерного анализа фациальных образцов и понимания процесса осадконакопления в ходе формирования бассейна.

The Donetsk basin is the southeastern part of the intracratonic Pripyat-Dniepr-Donetsk Rift-system, striking in a NW-SE direction from Belarus through Ukraine, over a distance of c. 1500 km the East-European Craton. The profiles of Late Carboniferous and Permian are characterised by interfingering marine-continental sediments in the Donetsk basin. Therefore, the possibility exists, to correlate the non-marine Carboniferous / Permian profiles of Western-Europe with the global marine stratigraphical scale. Detailed analyses of facies patterns and the reconstruction of the depositional setting are based on extensive fieldwork within the Donetsk basin. Microfacies analyses and micropalaeontological investigations of 110 limestone specimens were carried out. Furthermore, the straticraphic cross-sections (stratotype-key-section) of Upper Carboniferous and Lower Permian succession of Artemovsk area was correlated with the marine dominated stratotype section of the Pre-Donetsk basin, the well Skosyrskaya N 4199 (Alekseeva et al. 1983). The description of 2455 m of lithostratigraphic profiles of Makarov et al. (1985 a) and Aizenverg et al. (1975) and additional facies profiles of 51 wells of Makarov et al. (1985 b) were used together with own data to develop a sequence-stratigraphical deposition model of the Donetsk basin. The maximum flooding surfaces of the transgressive system tracts are represented by carbonate layers. The sequence boundaries correspond to bases of erosive fluvial channels. SB and mfs are distinctive horizons throughout the studied area. The results of facies analysis and the sequence-stratigraphical deposition-model were used to develop a relative sea-level curve of the Donetsk basin. The deposition-model of Izart et al. (1998) was specified. This was the base for the correlation of the relative sea-level curve of the Donetsk basin with the global sea-level curve as well as for the estimation of climatic fluctuations as controlling factors of the sea level fluctuations. A GOCAD-3D-model was developed to analyse the facies patterns in three dimensions and to understand subsidence processes during the basin evolution.

Introduction

Carboniferous and Permian sediments are globally mostly deposited in non-marine environments. Therefore marine/non-marine correlations are strongly hampered in the whole Pangaea, especially around the Carboniferous/Permian boundary. The Donetsk basin (DB) provides one of the rare transitional profiles with mixed marine/non-marine profiles of this time slice. Additionally, it forms the palaeogeographic link between the global marine standard and reference sections, as the Cis-Urals and the Moscow basin, and the pure continental basins in Central and Western Europe. Together with ongoing investigations of the non-marine fauna in the DB, detailed investigations of the facies patterns and the basin development, as presented here, are the base for future direct correlations of marine and terrestrial deposits.

Geological Setting

The Donetsk basin is the southeastern part of the intracratonic Pripyat-Dniepr-Donetsk Riftsystem (PDD), striking in a northwest-southeasterly direction from Belarus (Rostov/Don) through Ukraine, over a distance of ca. 1500 km the Precambrian East-European Craton (EEC).

The Upper Devonian PDD-System is characterized by a prerift phase, mainrift phase of Upper Devonian (includes Frasnian and Famenian) and postrift tectonic-sequences. These started between Devonian and Carboniferous, at the end of the Lower Visean, in the middle of Serpukhovian, in Permian and between Mesozoic and Caenozoic. The DB is located during the Upper Carboniferous in the area of subtropical – tropical trade wind zone northerly of the equator in a transition zone of humid equatorial climate in drier trade wind belt (Heckel 1999 a). Cyclic marine transgressions and regressions during Late Carboniferous and Early Permian as well as the transition from humid to increasingly dryer climate lead to characteristic lateral and vertical sequences of facies patterns. They consist of interbeddings and of marine, paralic-lagunal and continental deposits of coastal plain and shallow marine settings with thickness of 11.000 to 15.000 meters.

Monotonous sandstone, siltstone and claystone series with thin limestone and coal seam interlayers characterize the Upper Carboniferous (C_3) – Kasimovian and Gzhelian – and the lowest part of the Lower Permian (P_1). The sediments of the Lower Permian (Asselian and Sakmarian) differ strongly from the underlying and overlaying successions. Rock-salt seams characterize the Asselian and separate the clastic-carbonatic material, gypsums and anhydrite. That corresponds to the so-called «Gray zones» in the Ivano-Darievka outcrop.

Methodology

Detailed analyses of facies patterns and the reconstruction of the depositional setting are based on extensive fieldwork (in the Kalinovo, Mironovsk/Luganskoie and Ivano-Darievka outcrops), profiling and sampling in the Donetsk basin and additional extensive descriptions of stratigraphic cross-sections (stratotype-key-section) (2.455 m) (Makarov et al. 1985 a, Aizenverg et al. 1975) of the Upper Carboniferous and Lower Permian succession. Facies analyses and micropalaeontological investigations of 110 carbonate specimens were carried out. Own data, the results of facies analyses together with the description of the stratigraphic cross-sections were used to develop a sequence-stratigraphical deposition-model of the Donetsk basin. Cyclic sedimentation patterns have been analysed and correlated and their character and continuity were checked in facies intersections of 51 wells (Makarov et al. 1985 b). Furthermore, the stratigraphic cross-

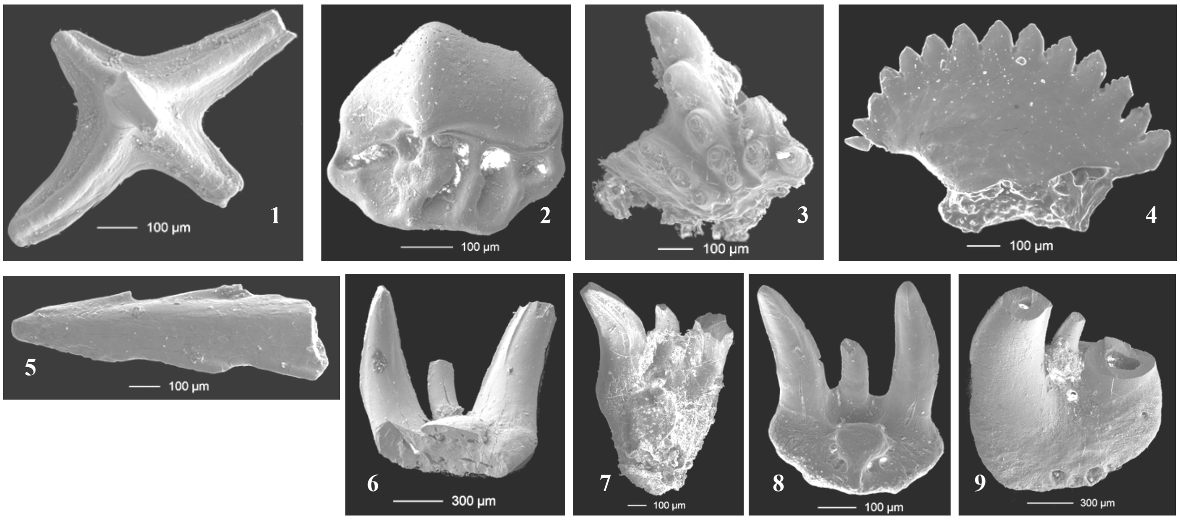

Fig.1. Isolated fish remains of the lacustrine limestone P_5 from the Kalinovo outcropd and P_6^0 from the Mironovsk outcrop of the Mironovsky Formation. 1 + 2 freshwater shark *Lissodus* – 1 *Lissodus* dermal denticle and 2 *Lissodus* tooth; 3 + 4 lungfish (dipnoan) tooth plate fragments; 5-9 Xenacanthid freshwater shark spine and teeth – 5 xenacanth dorsal spine, 6 to 9 xenacanth theeth – 6, 7 *Bohemiacanthus* sp., 8 *Xenacanthus* and 9 *Orthacanthus* indet. (Ritzmann 2004)

sections of Upper Carboniferous and Lower Permian succession of Artemovsk were correlated with the marine dominated stratotype section well (530 m) Skosyrskaya N 4199 (Alekseeva et al. 1983) of the Pre-Donetsk basin. This correlation was done by means of biostratigraphicaly data of both wells of Davydov et al. (2003).

Facies analysis

It was possible to distinguish in the O- and P-interval four lithic types (LT) of claystone facies, three LT of siltstone facies, five LT of sandstone facies, one coal facies and in the Q- to S-interval two types of interstratifications. These LTs were interpreted according to their palaeoenvironments and were correlated to facies associations with delta-front facies, lagunal and fluvial facies, lacustrine and swamp facies. The paralic deposits are dominated by thick fluvial successions which form delta systems by depositing sediments into the sea. The river deposits often consist of coarse-grained sediments and deposit first. Due to a successive fluvial sediment input formation suspension material in the area of the delta plain and in the basin area of the delta-front develops. Continuous sediment input during a relatively low sea level (LST) leads to a progradation of the shore line and to the formation of coarsening-upward sequences. Thick aggradate channel systems develop through high sediment input and missing accommodation space and cut laterally extensively in the deposits of the previous HST, for example in the intervals between the limestone layers O_3-O_4, O_4^4-O_4^6, O_7-O_8, P_5-P_5^0-P_5^1. Erosive conglomerates at the basis of fluvial channels consist of reworked and redeposited transgressive sediments of the previous sea level rise. Potential accommodation space displaces in the direction of the basin centre. The shelf consists more or less of eroded and fluvial material. Behind the shore line in the hanging layer of the older shore face and delta deposits the coast plain or the delta plain are located. They include the deposits of the fluvial flutes and scour channels, temporary lacustrine areas, swamps and coal formation. Because of the high sediment input and the missing accommodation space the shore line progrades or retrogrades respectively, if the accommodation space is build up faster, than it is filled up with sediment. In this way sand banks and lagoons are formed. During continuous sea level rise (TST) are the sand banks abraded and fill the lagoons. At the delta plain in swamps allochthonic plant material accumulates. Shallow, large lakes develop at the upper delta plain and are filled with fine-grained material. The delta plain sediments aggradate slowly on the top of the subsiding delta complex. The fluvial sediments on prograding alluvial plain consist of fluvial channel fills and fine grained deposits of flood plains. During a falling sea level a new prograding shore face develops which consists of fluvial sediments.

In a facies analysis of limestones in a marginal/shallow marine facies represented by the limestones O_4^3, O_4^6, O_5, O_6, O_6^0, O_6^1, O_7, P_1, P_2, P_3, P_4, P_6, Q to S and lacustrine facies with P_5, P_5^0, P_5^2, P_6^0, P_6^1, P_6^2 and P_7 could be distinguished. The micropalaeontological preparation of lacusrine limestone P_5 from the profile of the Kalinovo outcrop and limestone P_6^0 from the Mironovsk/Luganskoie outcrop shows first results. They prove the occurrence of Vertebrate – a highly diverse fish fauna with Palaeoniscid, Dipnoan or Crossopterygians, *Lissodus* and Xenacanthid – *Bohemiacanthus* sp., *Orthacanthus* indet. and *Xenacanthus* (Fig.1). It is important from a palaeogeographical point of view that so far this has been the only occurrence of Xenacanthid on the East-European Craton. The vertebrate fauna, the lithofacies and the smooth-shelled ostracoda and mollusc (Carbonicola-Type) are references for a fresh water facies. The results for the limestones P_5, P_5^0, P_5^2, P_6^0, P_6^1, P_6^2 and P_7 are not conform to the facies models by Makarov et al. (1985 a) and Izart et al. (1999), because they relate these limestones to a shallow marine, lagunal facies.

Sequence stratigraphy

A sequence-stratigraphical model with in three system tracts divided sequences has been designed (Fig.2) – lowstand (LST), transgressive (TST) and highstand (HST) system tract. The fluvial facies corresponds to LST-sediments, the facies associations 2, 3 und 4 to TST and the faciesassociations 1, 2 and 4 to HST of a sequence. The maximum flooding surface (mfs) of the transgressive system tracts are represented by carbonate layers. The sequence boundary (SB) is located at the basis of extensively erosive fluvial channels (beginning of the LST). SB and mfs are distinctive horizons throughout the studied area.

Correlation of the stratigraphic cross-sections (stratotype-key-section) of the Donetsk Basin with the well Skosyrskaya N 4199 of the Pre-Donetsk Basin

The limestone horizon O_8 of the well 4199 is equal to limestone P_2 of the stratigraphic

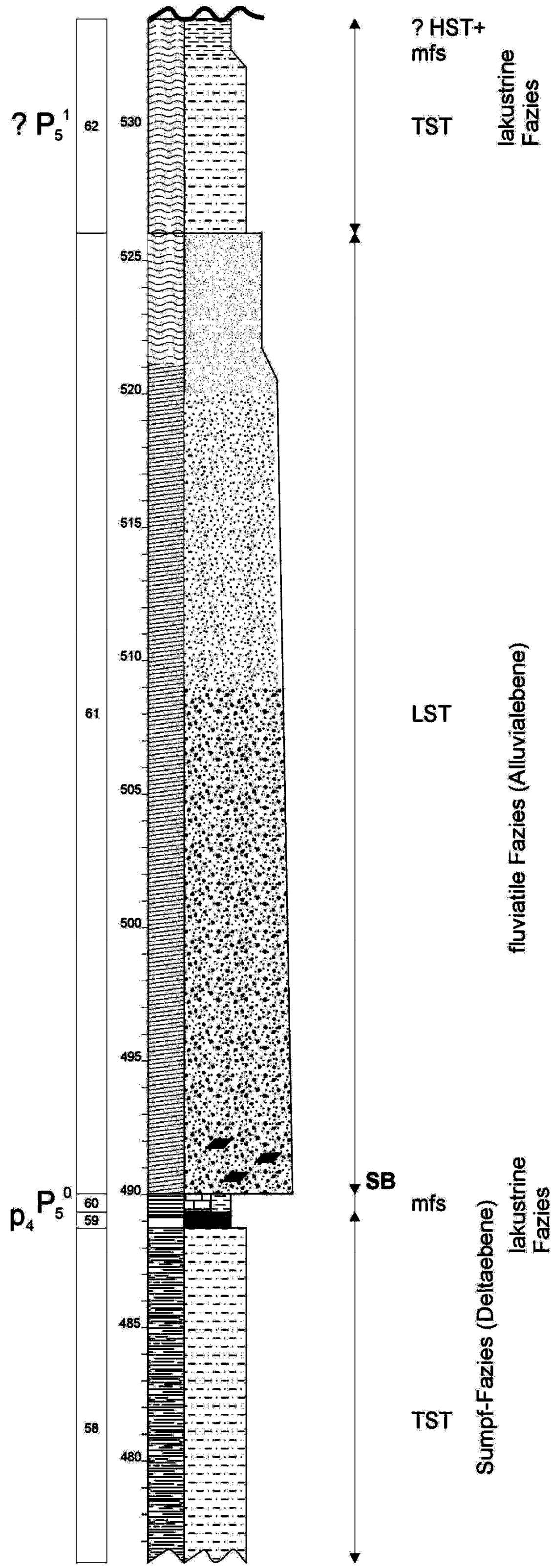

Fig.2. Example of typical sea level governed system tracts of the Donezk basin; profiles of the Mironovsk outcrops of the Mironovsky Formation; left level of the P_6, right level P_5 limestone marker horizon (Ritzmann 2004)

cross-section (stratotype-key-section) (Makarov et al. 1985 a, Aizenverg et al. 1975) after Davydov et al. (2003). Furthermore, the lithological unit (LU) 18 corresponds to LU 25, limestone P_1 to P_3, limestone P_2 to P_4, limestone P_4 to LU 50, the LU 53 to limestone P_5,limestone P_6 to underlaying by LU 57, limestone P_7 corresponds to P_5^0 and according to Davydov et al. (2003) limestone Q_{10} is equal to Q_7. In each case, the first unit or the first named limestone horizon respectively belong to well Skosyrskaya N 4199 (Alekseeva et al. 1983) and the second named unit belongs to the stratigraphic cross-sections (Makarov et al. 1985 a, Aizenverg et al. 1975) of the Donetsk basin.

GOCAD-3D-Model

A GOCAD-3D-model was developed to analyse the facies patterns in three dimensions and to understand subsidence processes during the basin evolution. The model is based on data from 51 wells (Makarov et al. 1985 b). In the three dimensions model is the course of the NW-SE direction of the rift axis is clearly visible. The model shows sedimentary bodies which correspond to marine facies, lagunal facies, fluvial facies partly together with swamp facies and lacustrine facies. Furthermore, the facies patterns, the lateral and vertical formation and distribution of the facies is apparent.

Thus it appears that the marine facies and lagunal facies dominate in the O-interval, whereas fluvial and lacustrine facies dominate in the P-interval. In the upper part of the P-interval the fluvial and lacustrine sediments form thick sedimentary bodies.

Synthesis / Conclusion

The synthesis of the results of facies analysis, the sequence-stratigraphical model and the correlation of the wells are the basis for the development of a regional sea level curve for the Donetsk basin. The sequences reflected high-frequency transgression and regression events. Fourth order sequences could be developed from this. The O- und P-interval were subdivided into 12 and the Q- to S-interval into 11 fourth order sequences. The deposition-model of Izart et al. (1998 a) was specified. Thus the requirements for correlate this relative sea-level curve of the Donetsk basin with the global sea-level curve and to estimating the climatic fluctuations as controlling factors of the sea level fluctuations have been created.

Acknowledgements

The investigations were carried out within the frame of the Double-Diploma-Program between the Technische Universität Bergakademie Freiberg and Moscow State Geological Prospecting Academy. The financial support by the German Academic Exchange Service as well as Tempus Tacis is gratefully acknowledged. I thank Prof. Dr. J.W.Schneider, Technische Universität Bergakademie Freiberg, Prof. Dr. V.R.Lozovsky, Moscow State Geological Prospecting Academy as well as the late Prof. O.Fissunenko, Lugansk (Ulkraine) for their supervisions of the diploma thesis and the common field work and Prof. Fissunenko especially for providing important research results.

LITERATURE

Aizenverg D.E., Lagutina V.V., Levenstein M.L. & Popov V.S. (Hrsg./eds.) (1975): Putevoditel ekskursii po Donetzkomu bassejnu.- Izd. «Nauka» Moskva, 360 S., 67 Abb. (in Russisch und Englisch) – Field excursion guidebook for the Donets Basin.- «Nauka», Moskva: 360 pp. (in Russian and English).

Alekseeva I.A., Glushenko N.V., Ivanov V.K., Inosova K.I., Kalmykova M.A., Kashik D.S., Kozitskaja R.J., Krusina A.KH., Movshovich E.V., Reditchenkin N.A. & Shvartsman E.G. (1983): Key section of boundary Carboniferous and Permian beds of the south of the eastern-European Platform (Gzhelian and Asselian stage), SKOSYRSKAYA borehole N 4199 – Leningrad «Nauka» 1983, 123 pp.

Davydov V.I. & Leven E.J. (2003): Correlation of Upper Carboniferous (Pennsylvanian) and Lower Permian (Cisuralian) marine deposits of the Peri-Thetys.- In: Palaeogeography, Palaeoclimatology, Palaeoecology 196 (2003); p.39-57.

Heckel P.H. (1999 a): Overview of Pennsylvanian cyclothems in midcontinent North America and brief summary of those elsewhere in the world.- In: Carboniferous and Permian of the World, L.V.Hills, C.M.Henderson, and E.W.Bamber (editors), Canadian Society of Petroleum Geologists, Memoir 19, p.79-98.

Izart A., Briand C., Vaslet D., Vachard D., Broutin J., Coquel R., Maslo A., Maslo N. & Kositskaya R. (1998 a): Stratigraphy and sequence stratigraphy of the Upper Carboniferous and Lower Permian in the Donets Basin.- In: S.Crasquin-Soleau & E.Barrier (eds.), Stratigraphy and evolution of Peri-Tethyan platforms. Peri-Tethys Memoir 3. – Mem. Mus. Nat. Hist. nat., Paris, 177, p.9-33.

Izart A., Vachard D., Vaslet D. & Maslo A. (1999): Sedimentology of the Upper Carboniferous and Lower Permian in the Dniepr and Donets Basin.- In: Carboniferous and

Permian of the World, L.V.Hills, C.M.Henderson, and E.W.Bamber (eds), Canadian Society of Petroleum Geologists, Memoir 19, p.120-143.

Makarov I.A. (eds) et al. (1985 a): Description of the straticraphic cross-sections of the upper Carboniferous of the Donets basin. Ukraine Geological Ministery, PGO Donbas Geology, Artemovsk GPE, Tom 1, Text. (in Russian).

Makarov et al. (1985 b): Description of the straticraphic cross-sections of the upper Carboniferous of the Donets basin. Ukraine Geological Ministery, PGO Donbas Geology, Artemovsk GPE. (in Russian), Tom 2 (in Russian).

Stovba S., *Stephenson R.A*., & *Kivshik M*. (1996): Structural features and evolution of the Dniepr-Donets Basin, Ukraine, from regional seismic reflection profiles.- In*:* Stephenson, R.A., Wilson, M., de Boorder, H. & Starostenko, V.I. (eds.), EUROPROBE: Intraplate Tectonics and Basin Dynamics of the Eastern European Plattform. Tectonophysics, Volume 268, Issue 1-4, 15th January 1997, p.125-147.

Stovba S. & *Stephenson R.A*. (1999): The Donbas Foldbelt: its relationship with the uninverted Donets segment of the Dniepr-Donets Basin, Ukraine.- In: Tectonophysics, Volume 313 (1999), p.59-83.