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Automicrites, Buildups, and Reservoir Shaping in Late Devonian Basins Of the East European Craton

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Summary

The East European Craton (EEC; also known as Baltica or Russian Platform) is one of major circum-Arctic continental blocks bearing important Paleozoic hydrocarbon basins yet with many blank spots in their facies and paleogeography. During the middle Frasnian through Famennian, eastern and central EEC was covered by an epeiric to platform-margin basin where carbonate deposition was controlled by the mudmound factory (*sensu* Schlager, 2003). Automicrites, automicrite-rich skeletal boundstones, syngenetically lithified muds, and the products of microbial micritization dominate the facies spectrum from basinal through biohermal to intertidal setting which was favored by dominantly low-energy, mesotrophic to eutrophic regimes, along with enhanced ability of marine microbial mats to calcify. The Late Devonian carbonate mounds and coalesced carbonate platforms tend to form highly fractured reservoirs and control the drape traps in the overlying strata.

Tectonic structure and paleogeography

The East European Craton (EEC; also known as Baltica or Russian Platform) is one of major circum-Arctic continental blocks bearing important Paleozoic hydrocarbon basins. The Timan-Pechora (TP) and Volga-Uralian (VU) hydrocarbon provinces of the EEC have an interconnected history of Late Paleozoic development. During the middle Frasnian through Famennian (Late Devonian), both represented broadly connected, equatorial to low northern latitude, intracratonic basins, open to the back-arc basin of the contracting Uralian Ocean (Fig. 1). The moderate to high subsidence rate, markedly different due to Devonian cratonic rifting (peaking in Middle – early Late Devonian), moderate and intermittent siliciclastic influx, and extensive growth of sedimentary carbonates, has created the complex seafloor topography with a single off-Timan basin in the TP and a branching system of strait-like basins in the VU named Kama-Kinel’ System of Depressions (Fig. 1). Organic matter accumulation in these basins created the main hydrocarbon source for both provinces. The morphology of the mid-Frasnian to Famennian carbonate bodies corresponds to pinnacles, groups and chains of pinnacles regarded as “atolls” and “reef tracts”, and extensive carbonate platforms (shelves) reaching the thickness of 0.5-1 km in their mid-Frasnian through Famennian parts. These buildups, unevenly affected by dolomitization and sulphatization, tend to form highly fractured reservoirs and shape the drape traps in the overlaying strata. To the present-day west, the VU seaway graded into the epeiric Moscow carbonate sea (MS) which lacks basinal source rocks and seismic-scale buildups.

Data set

In the last few years, 21 wells from TNK-BP licenses across the Bobrovka-Pokrovskoe carbonate platform of southern VU (Fig. 1) has provided over 500 m of the Upper Devonian carbonate core (and even more from the Tournaisian). Elsewhere, data have been obtained from the eastern TP (seismics, well logs and fragmentary core) and the outcrop observations in the Western Urals, southern MS, and the southern Timan. Our ideas confirm, often implicitly, facies descriptions available in the literature and unpublished reports.

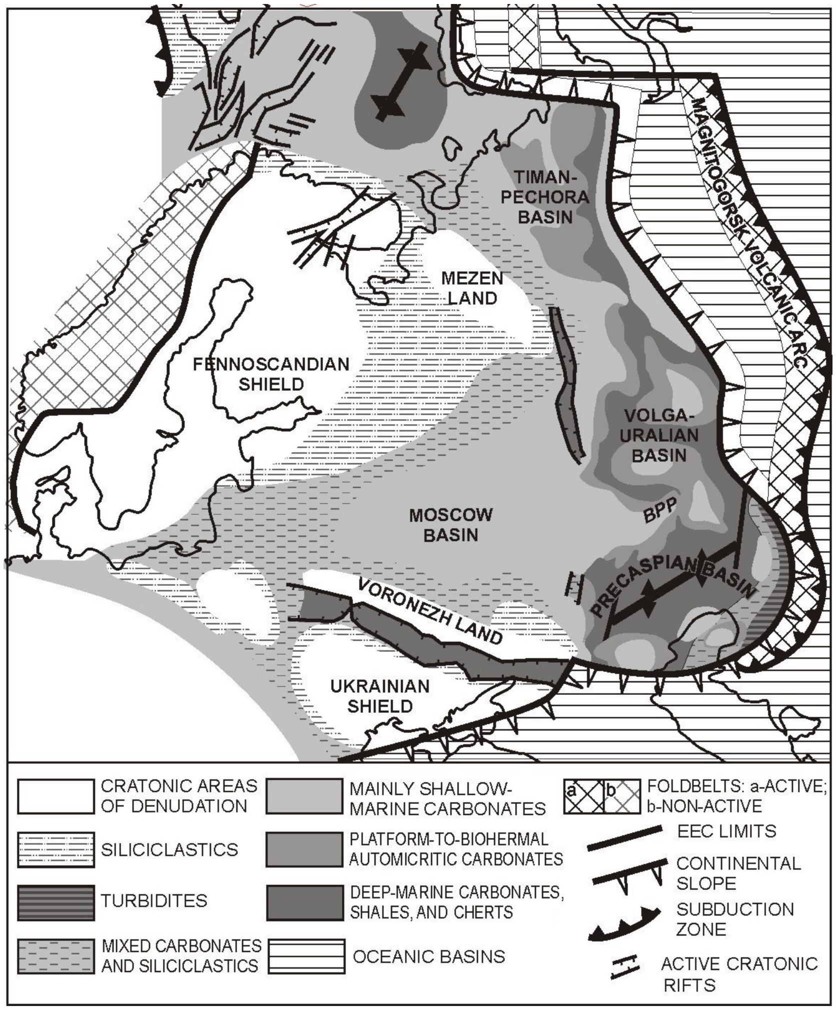

Figure 1: Late Frasnian - Famennian paleogeography of EEC (based on Nikishin et al., 1996); *BPP* is Bobrovka-Pokrovskoe carbonate platform

Bobrovka-Pokrovskoe Carbonate Platform (BPP)

The BPP forms the southern flank of the Mukhanovo-Erokhovka Depression, a part of the Kama-Kinel' system. It is expressed as a positive sublatitudinal feature reaching 160x30 km. The BPP formation is mostly accounted for by the late Frasnian through Tournaisian accretion of carbonates (up to 900 m) starting from separate bioherms and in Famennian-Tournaisian evolving into the coalescent carbonate platform which prograded onto the Mukhanovo-Erokhovka basin where the equivalent strata shrink to 300 m. New seismic data suggest the presence of carbonate pinnacles within the basin. The platform slope dips at 20-30°. The facies zonality of the BPP recognizes the “barrier-reef” (in fact probably the platform-flank), biohermal-shelfal, and shelfal zones (Panteleev et al., 1997). Lithofacies research has been focused on the Middle-Upper Famennian core from the Bogolyubovka and Ananievskaya fields representing the biohermal-shelfal to shelfal zones, the Gerasimovka field (“barrier-reef” zone), and the Peshkovskaya field representing the laminated marls from the basinal straight draping the drowned Late Frasnian buildup.

Lithofacies

The lithofacies of the BPP core and those reviewed from elsewhere in the TP, VU, and MS are distinct on the basis of extensive development of automicrites (the non-skeletal micrites of syngenetic lithification involving organomicritization) with variable quantities of bioclastic material and algae, notably rich in micritized grains and calcispheres. The reefal facies are usually represented by the coral, stromatoporoid, parachaetetid, and algal boundstones with various proportion of automicrites. Other carbonate-platform facies are (1) peloid, intraclast, oncoid-rich grainstones and rudstones, (2) nodular wackestones with non-compacted intranodule domains, (3) massive, nodular, slightly stromatoidal automicrites, and (4) distinctive fenestral (bird's eye) automicrites with thromboid-to-stromatoid fabrics ("sfero-uzorchatyi limestone"). Group (4) intergrades with (5) fenestral stromatoidal laminites, often with erosional surfaces, solution-enhanced fenestrae and cracks suggesting intertidal origin. A distinct feature is the apparent rarity (lack in our materials) of the fore-reef breccia in the platform-slope core (VU and TP), although such "fore-reef" aprons are sometimes put into geological models under the influence of reef concept. Across the Frasnian/Famennian boundary, skeletal boundstones decline giving way to non-skeletal automicrites with scattered skeletal frame-builders. The mud-mound nature of these biolithites have been admitted (e.g. Mikhailova, 1987), however, with little echo in the regional exploration geology. In the shallow subtidal epeiric areas of the MS, fenestral lithofacies are rare. In the facies of early micritic lithification, the sessile benthos (brachiopods, etc.) is often immured in life position, bioturbation seems to be depressed, sometimes absent.

In the Famennian portion of the BPP, the shelfal zone is dominated by fine-grained grainstones with thin (< 0.5 m) stromatoporoid boundstones and massive nodular mudstones-to-automicrites. The latter seems to be the deepest within the shelfal facies zone. The core attributed to the biohermal-shelfal zone consists of bird's-eye "sfero-uzorchatyi" automicrite, stromatoidal laminites, and peloid-rich grainstones-rudstones. The reflecting horizons acquired close to the Famennian top and the middle Frasnian – Famennian δT maps from the BPP interior have uneven, hummocky appearance. The hummocks are less than 3 km wide, with gentle slope angles not steeper than 12º. Hummocky expression of Upper Devonian surfaces are widely reported across the VU and TP and are commonly attributed to reef pinnacles. One well from the Gerasimovka field provides the core for the upper Famennian platform-slope ("barrier-reef") facies. This core is pervasively dolomitized, retaining large stromatactis with geopetals oriented at 20-60% angle to the horizontal. Large cavities and fissures are occluded by sucrosic anhydrite cement. The gradual transition from automicritic to bioclastic facies is recorded by the Tournaisian core from the shelfal facies zone.

Reservoir properties

The reservoir properties in Frasnian-Famennian carbonates are often controlled by enhanced formational fracturing. Touching-vug (cavernous-fractured in Russian terminology) reservoirs are common. Pore systems show complexity and are variously contributed by residual fenestral (in automicrites), intergranular (in grainstones), vuggy to cavernous, and intercrystalline dolomitic pore space. In the surveyed BPP core, dissolution vugs and caverns seem to have formed mainly by burial diagenetic rather than meteoric processes. In the review of VU Devonian reservoirs, Aliev et al. (1978) reported mean K_p 1-25% for middle Frasnian through Famennian carbonate productive layers, whereas K_{pm} averages 1-8 mD (peaking at 1000 mD) in the Famennian, 1-320 mD in the upper Frasnian, and 0.1-75 mD in the middle Frasnian. 3D fracture density is 1-80 m^{-1} in the Famennian, increasing to 55-120 m^{-1} in the upper Frasnian and 20-150 m^{-1} in the middle Frasnian data set (Aliev et al., 1978). Our plug dataset from the upper Famennian of the BPP shows average K_p 1-17% and K_{pm} up to 464 mD for the grainstone-dominated shelfal facies zone. The automicrite-dominated biohermal-shelfal zone shows K_p 1-

12%, K_{pm} up to 30 mD, and enhanced fracturation. A dolomitized core from the Gerasimovka platform-slope facies zone features K_p up to 8,4%, K_{pm} up to 9,5 mD, and very high fracturation.

Conclusions

During the middle Frasnian through Famennian, eastern and central EEC was covered by an epeiric to platform-margin basin where carbonate deposition was controlled by the mudmound factory (*sensu* Schlager, 2003). Automicrites, automicrite-rich skeletal boundstones, syngenetically lithified muds, and the products of microbial micritization dominate the facies spectrum from basinal through biohermal to intertidal setting which was favored by dominantly low-energy, mesotrophic to eutrophic regimes, along with enhanced ability of marine microbial mats to calcify. The Late Devonian carbonate mounds and coalesced carbonate platforms tend to form highly fractured reservoirs and control the drape traps in the overlying strata. Integration of mudmound concept into regional facies models will improve predictability of carbonate reservoirs on many scales.

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