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NEW STAGE OF HYDROCARBON EXPLORATION IN THE BLACK SEA BASIN: UPDATING OF ITS GEOLOGICAL STRUCTURE AND PROSPECTS DEVELOPMENT

The Black Sea basin is one of the last immature but closest to the European market hydrocarbon exploration frontier with rather high petroleum potential assessment. Several factors, including the understanding of its tectonic and sedimentary evolution, postpone a full-scale development of oil and gas prospects including deepwater sub-hydrate gas accumulations and shale gas resources in the circum-Black Sea region. The geological risks of its development based on recent exploration activity results are analyzed.

Keywords: Black Sea, exploration well, thermal maturity, hydrocarbon resources, tectonic evolution, deepwater sedimentation, reservoir rocks, gas hydrates.

Introduction. As well known, the Black Sea basin is one of last exploration frontiers close to European market and it is still immature one despite of 40+ years of exploration efforts bearing high share of geological risk. It means three-way risk, namely the chances to drill dry well, to discover marginal non-commercial field or deviate from an optimal development of discovered field. Comparisons claiming that the Black Sea is the second North Sea (that developed for long time arm-in-arm with progress in petroleum geology, offshore exploration techniques and tools) are far from reality. This analogy is incorrect not because the North Sea is slightly bigger (1.6 times) that Black one. The basic advantages of the former one are shallow-water settings, basinwide development of several reservoir strata, an existence of aborted paleorift system with thinned continental crust underneath producing higher heat flow density due to thermal postrift rejuvenation accompanied by moderate crustal seismicity, and finally, the neighboring developed nations have set and concerted their maritime boundaries of exclusive economic zones at early exploration stage. Nothing like that is valid for the Black Sea basin. Nevertheless, exploration potential of the Black Sea for hydrocarbons is estimated rather high upon direct geological analogy and spatial to the South Caspian basin. Despite of such similarity the Black Sea also lacks certain basic features that make the South Caspian basin a prolific petroleum province.

New exploration results. Last five years might become a turning point in exploration development of the Black Sea basin because ambitious plans for deepwater exploration have started to materialize (Fig. 1). By modern and brand new deepwater drilling rigs and vessels of 5^{th} and 6^{th} generations it was drilled 4 deepwater exploratory wells in the Turkish waters, namely Sinop-1, Yassyhoyuk-1, Sürmene-1 (close to the first deepwater well in the region, HPX-1), and Kastamonu-1. All of them have delivered no commercial productivity, only gas and oil shows due to lack or tight (Campanian volcaniclastics for Sinop-1 well) reservoirs or inexact geological models, though such criteria as enough structural elevation, bright seismic spots or gas chimneys as well as petroleum system modeling were available. Due to such a negative result further planned deepwater exploration drilling was suspended. Indirectly this has deferred exploration drilling on the Shatsky ridge to the Upper Jurassic carbonate build-ups prospect in the Russian sector (Maria prospect). Anyway, despite of the result it is important that Sürmene-1 well has revealed a live petroleum system in the Maykopian sequence accompanied by the abnormal formation pressure.

Kaliakra East-1 exploratory well drilled in the Galata license block in the Bulgarian shelf (Lower Kamchia sub-basin) did not proved presence of Paleocene reservoir and was abandoned as well as Kamchia-1 one (Petroseltic Int. plc).

The Pontian sandstones with commercial gas pools of Doina and Ana fields (Midia license block) in the Romanian shelf have demonstrated a transition of fine-grained sandstones into

low permeable siltstones in well Ioana-1 so additional reinterpretation of seismic data and exploratory drilling is planned there.

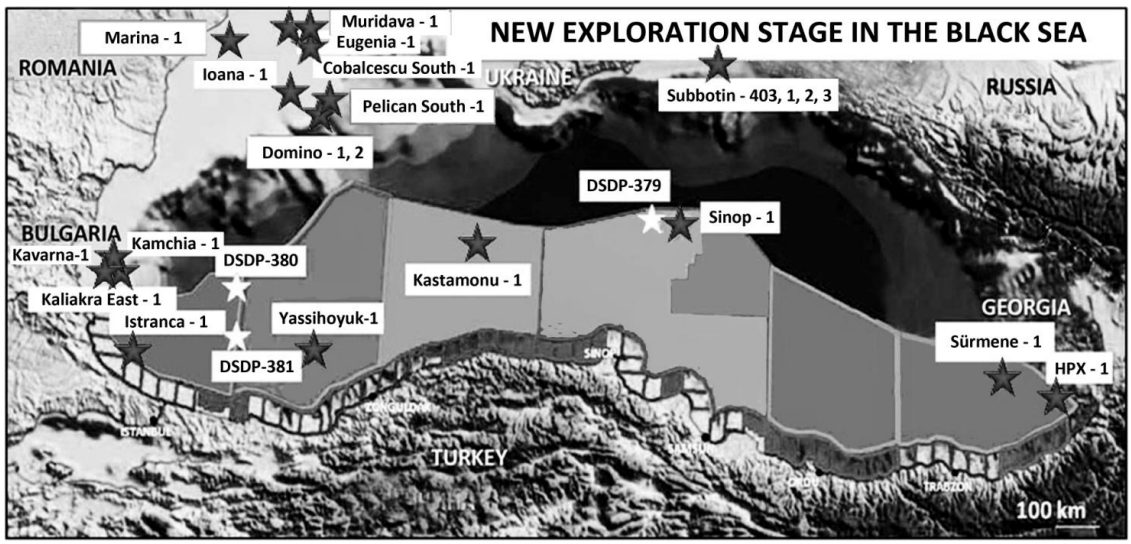

Figure 1. Exploratory drilling of new stage in the Black Sea, black stars, DSDP wells are shown as white, and shaded sectors are license permits in the Turkish waters.

Within Turkish waters only several small gas fields in the Eocene turbidites (Akcakoca South sub-basin west of Istanbul) have proven recoverable gas reserves. In the Turkish shelf close to Bulgarian waters Istranca-1 exploratory well has discovered a gas pool in the Mid-Miocene limestones, but only pilot testing can prove its commercial viability because neighboring wells Limankoy-1 and 2 have demonstrated marginal productivity from Miocene carbonates. The Domino-1 and 2 wells (Neptun license block, OMV Petrom/ExxonMobil) were drilled on the hinge of Romanian continental slope, see Fig. 2. The well-logging of Domino-1 well spudded at 970 m water column depth has revealed of 70 m net thickness of the gas-saturated Pontian sandstones allowing estimation of recoverable reserves at 42÷84 Bcm; its stratigraphic position is shown on Fig. 3. The shallow water exploration well Marina-1 was recently drilled 60 km from Romanian shore, within Istria XVIII Perimeter, to a depth of about 2150 meters below the seabed. First estimates from production tests show a potential production per well of 1,500 – 2,000 boe/day. After the completion of tests, the Marina-1 well will be plugged with cement and abandoned. OMV Petrom is currently exploiting five reservoirs: Pescarus, Lebada East, Lebada West, Sinoe and Delta. These have a total production of about 31,000 boe/day. The Ocean Endeavour rig is drilling now the Pelican South-1 wildcat well about 155 km offshore in the Romanian sector of the Black Sea.

Rather important from geological viewpoint is the gas discovery made in the Pelican license block by Sterling Resources Ltd. (now is merged with Petroseltic Int. plc) in the area that been arbitrated to Romania's exclusive economic zone according to the decision by the Hague Court. TWD of Eugenia-1 well (within former Mushketov prospect) is 2776 m at 28 m water column depth. Two Upper Cretaceous (Maastrichtian) gas-bearing intervals with 55-62% gas saturation of 22 m net thickness were revealed by well-logging at 1938-2038 m depth. Besides, gas manifestations were detected while drilling through Eocene limestones (commercial flow rates are known from Olympiyska prospect nearby) on the depth of 1900-1938 m. Some minor gas shows have also been registered while drilling through Oligocene strata (submarine paleo-slide body) where sandstone net thickness reaches up to 100 m. It is predicted that optimal entrapment conditions for the Oligocene reservoir occur nearby in the deep Eugenia South prospect. Two other wells were drilled in 2013/14, on the trend with

existing discoveries. Cobalcescu South-1 well has encountered two Miocene targets – a good quality reservoir - but without commercial quantities of hydrocarbons, and Muridava -1 well has revealed Eocene, Paleocene and Cretaceous targets, but failed to encounter commercial quantities of hydrocarbons.

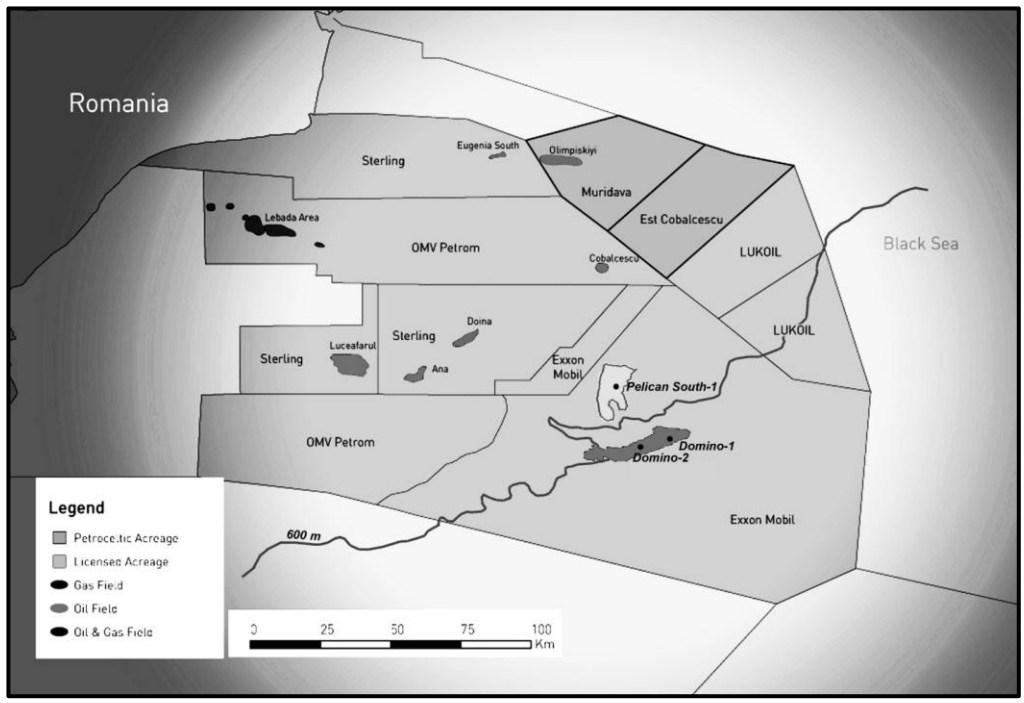

Figure 2. Oil and gas discoveries offshore Romania.

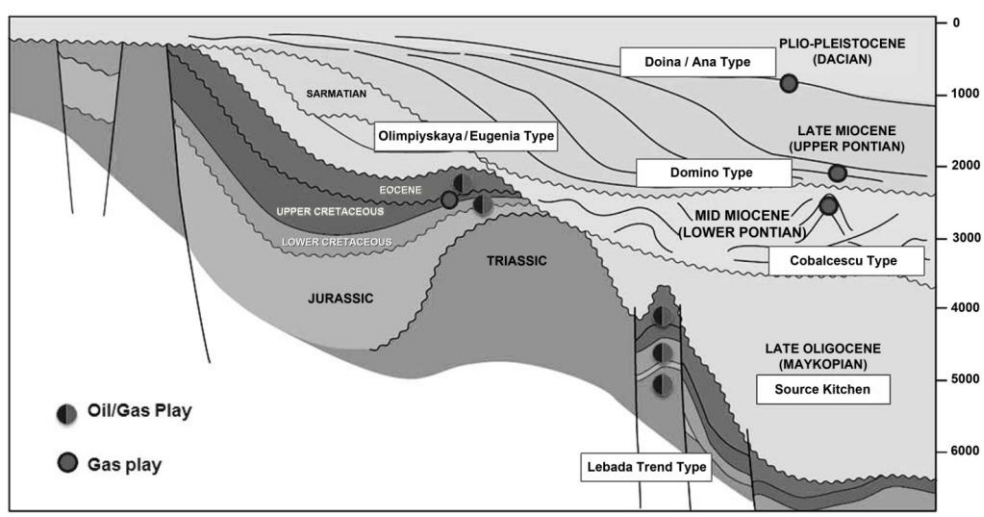

Figure 3. Tectonisedimentary model of the Romanian offshore vs. its proven hydrocarbon plays [13], modified.

From all countries sharing the Black Sea only Ukraine still possesses an extensive easy-to-explore shallow-water portfolio for almost 70 structural/stratigraphic mid-sized and small prospects within mobile inner shelf of the Odessa Gulf and 30 ones in the Sea of Azov plus two dozen of thrust and pop-up anticlines along WSW-ENE transpressional structural trends south

of Kerch Peninsula, and the mid-water Pallas uplift, a submarine continuation of submerging structures of the Western Caucasus orogen.

Other promising prospects, namely thrust anticlines with Maykop piercing cores in the Sorokin trough, structural traps of the northwestern continental slope/toe and, naturally, basinal shallow and deep-seated prospects require deepwater drilling rigs. However, discovery of a Lebada-type field in the Lower Cretaceous synrift sequence is still awaited within the Odessa shelf. A separate exploration problem is a broad shoal water area in the Gulf of Odessa and Sea of Azov, which is practically unstudied by seismic exploration and untested by drilling. For example, Priazovske gas field onshore the Sea of Azov is discovered in the shallow Lower Sarmatian sands. From other hand, recent discovery of Subbotin oil field offshore Kerch Peninsula is faced with strong complexity of reservoir compartmentalization due to multi-stacking (due to thrusting) of Maykop reservoir rocks and their spatial heterogeneity (clinoforms), thus much should be done further to understand detail tectonic and sedimentary structure of the Peri-Kerch shelf.

Key exploration challenges. The assessments of the Black Sea petroleum potential at 10-12 Bcm by TPAO experts of recoverable oil equivalent (as a maximum) or so are still speculative one and the advance of modern ultradeep drilling to the basin did not resolve the ambiguity yet. As to the geological obstacles postponing reliable exploration success these are as follows.

- Most of the basin area is a deepwater domain with 1000-2200 m of water column so its exploration requires significant long-term capex investments into seismic surveying, drilling and field development;
- The basin lacks reservoir rocks and their spatial development is very uncertain; to find high quality reservoir is quite equal to discover a hydrocarbon field;
- Low heat flow is characteristic of the basin limiting due organic matter maturation at moderate depth; only the circum-Black Sea transition zone from continental to oceanic crust has suitable maturation values in some places;
- Comparing to the North Sea basin the Black Sea one has passed drift stage and dissipated its initial thermal impulse during synrift and drift stages for intense volcanic activity without secondary rejuvenation, moreover, an extra lithospheric plunging due to steady approaching of the Arabian plate to Eurasia affects the basin since Oligocene time;
- Except of the Maykop source rocks (and Upper Eocene ones with some limitations) all other potential intervals demonstrate suitable generation parameters only sporadically on the depth testable by conventional drilling and the basin is mainly considered as gas-bearing one charged with methane of mixed biogenic-thermogenic origin;
- Anomalous thickness of Pleistocene-Holocene sediments, submarine canyons and slides, as well as local presence of gas hydrates and mud volcanoes complicate geotechnical exploration conditions within the continental slope and depocentral part of the basin; abnormally high formation pressure in many deepwater localities is a challenging factor;
- Mainly peripheral tectonic inversion and absence of evaporitic seal rocks (there are evidences for Messinian or pre-Pliocene unconformity only) have limited basinwide development of conventional traps quality and variety despite the Black Sea is one of the gassiest basins in the world; buried synrift Mesozoic horsts do not produce high-amplitude swells in the Cenozoic sedimentary fill;
- Peripheral uplifts like the Marginal Terrace, Tetyaev and Shatsky swells, Polshkov and Druzhba highs as well as buried front of the Pontides have captured a clastic sedimentary flux from the landmasses from time to time that limited a basinwide reservoir rocks distribution.
- The basin is standing now at the initial stages of its hydrocarbon potential realization.

It is necessary to add to this that environment of this semi-closed water basin is extremely vulnerable and unsolved problems with delimitation of economic zones in some sectors of the Black Sea retain socio-political risks for its hydrocarbon exploration. Also, it is

worth to emphasize an absence analogs in the Black Sea of powerful Pliocene rivers like paleo-Volga that drained vast area of the East European craton (that time paleo-Dnieper was a tributary of paleo-Volga river) and crossed the Northern and Central Caspian parts and then spilled the powerful clastic material flux over the Absheron-Peri-Balkhan- threshold into the South Caspian basin. All potential analogs in the Black sea are much smaller. Secondly, the Black Sea lacks quite prominent secondary structural splay of post-Maykop-Holocene trends characteristic of the South Caspian basin splitting from the Greater Caucasus and Kopet-Dag orogens and gradually fading basinward thus developing world-class structural hydrocarbon traps. Thirdly, the mud volcanism is much powerful in the South Caspian basin and represented not only by fold-and- fault-related mud conduits piercing the strata, but it is associated with structurally important Maykopian shale anticlines and cupolas. Finally, it is recently proved an active subduction process (favorable for petroleum generation) of the South Caspian microplate under the Scythian-Turan platform while the similar activity offshore the Crimea and Caucasus is ceased and focal mechanisms of earthquakes mainly correspond to oblique normal faulting or strike-slip movements.

So the question is where a hydrocarbon “sleeping giant” could be found in the Black Sea is an actual one At the moment good choices are a bit restricted. Answering this one should take into account that size of mapped structures matters and multistage hydrocarbon column is a function of structural elevation of the trap. Plus, known hydrocarbon filling (above spill point) of the traps for already discovered fields in the shelfal zone of the Black Sea is not so optimistic. Additionally, the thermal models on source rocks maturity have demonstrated the fit between two end member scenarios (a “hot” and a “cold” model). Whereas the “hot” model provides good results in the shallow water areas, the “cold” model is considered more valid for the deep-water areas of the Western Black Sea depression [11].

New exploration targets. Of course, one dry well is not interposing the exploration veto on exploration within rather long and high the Andrusov Swell, a mid-Black Sea buried ridge. A top priority prospects capable to host large hydrocarbon reserves are mapped along the Gudauta-Shatsky Swell, Pallas High and Tetyaev Uplift in the Eastern sub-basin. Numerous anticline folds in the Tuapse and Sorokin troughs, and gravity-driven submarine rollovers offshore Romania and Bulgaria have a nice exploration potential, however, rather scattered. Another option is to search for deepwater clastic fans. Taking into account some limitation stated above, the most promising exploration zone in the West Black Sea sub-basin is confined to the outer shelf or continental slope, where the heat flow values, deepwater facies settings favorable for higher TOC content and clastic transport discharge area are superimposed (Fig. 4).

To illustrate this concept the result of 3D joint inversion of seismic and geodensity data is shown on Fig. 5, which is make possible to delineate a huge ultradeep prospect under the waters of Skifska license block [5, 12]. The contour of lower density domain that has been mapped there speaks in favor of deepwater clastic fan (Albian or Valanginian in age [2]) that has been sourced from the paleo-rivers fed from the Cimmerian orogen in the Crimean. Those alluvial streams run to the west along the synrift graben and then turning left have crossed the Marginal Terrace barrier near the West Crimean Fault zone through incised canyon and then splayed over the newborn basin paleo-floor.

Such favorable conditions for sedimentary flux input are known for the Histria and Lower Kamchia troughs (aborted paleorift arms) [8]. Some similar conditions are expected along basinward continuation of Bosporus channel for Miocene and younger sequences. In the Eastern sub-basin the Kerch Strait channel with paleo-Don river submarine clastic fan and the Lower Rioni sub-basin opening to the Black sea are also are of high exploration potential.

Except of conventional hydrocarbon resources the Black Sea region has exploration potential for the unconventionals as well. For example, first shale/tight gas prospects can include the Upper Jurassic – Lower Cretaceous Chaglayan turbiditic sandstone-shale formation of 2000 m thick onshore the Northern Turkey or the Cenomanian-Turonian transition interval with the Aksu-Dere black shales of the Karkinit trough onshore Tarkhankut Peninsula.

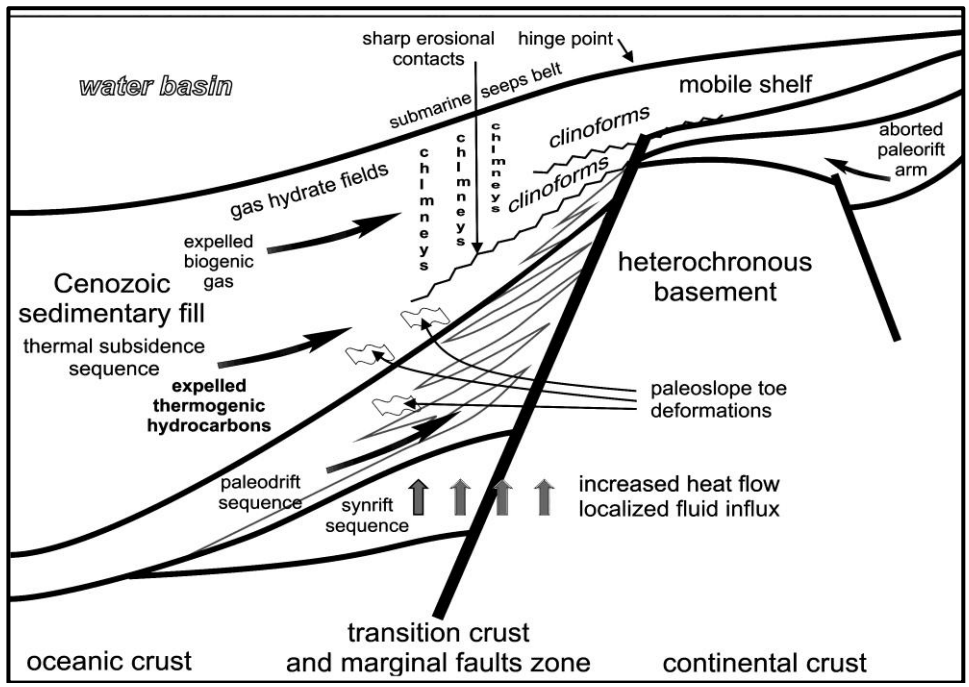

Figure 4. Conceptual model of a marginal sedimentary prism, the most promising exploration zone in the Black Sea, passive margin settings (out of scale).

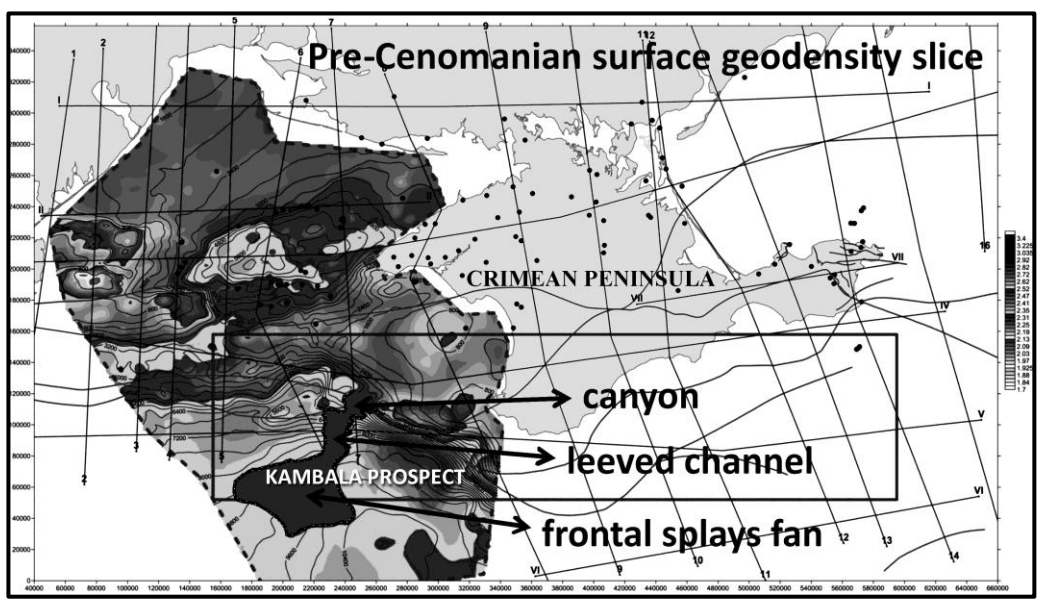

Figure 5. Deepwater Neocomian-Albian (?) deepwater fan (Skifska license block) by 3D joint inversion of seismic and gravity data, featuring lower density domains including deepwater Kambala prospect [12].

Though first successful pilot test to produce methane from submarine gas hydrate field in the East Nankai trough offshore Japan has resumed practical interest to developing of giant gas hydrate potential of the World Ocean and the Black Sea basin as well, this kind of unconventional resources still requires an extensive study and development of commercially viable and environmental safe recovery technique. By different experts the methane hydrates

recoverable reserves estimations (from proven gas hydrate fields) vary in a very broad range that reflects the current state of knowledge of their occurrence in the Black Sea. Keeping aside the problem of commercial recovery of methane from gas hydrate seams, lenses and nodules of muddy bottom sediments till suitable times, it worth to focus onto sub-hydrate zone of free gas in conventional Pleistocene reservoirs, because sediments bearing gas hydrates represent an effective seal for upward fluxed of thermogenic gas along fault conduits [3]. An example (Fig. 6) of hydrate-screened trap in the Ukrainian part of the northeastern slope demonstrates the occurrence of a combined free gas trap under hydrate stability zone (bottom simulating reflector).

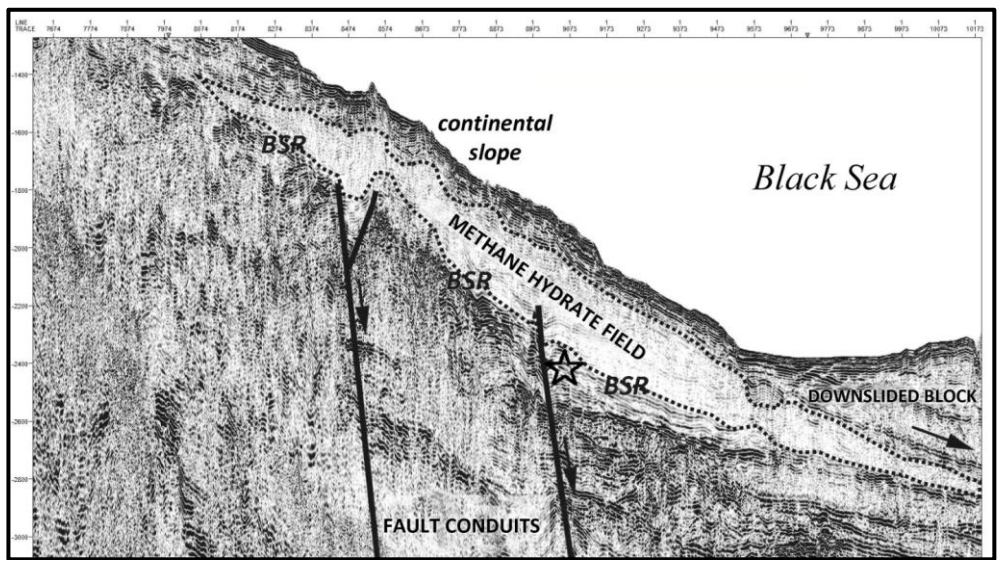

Figure 6. An example of gas hydrates occurrence, the northwestern continental slope, Black sea, seismic line BS-05-26. Note potential sub-hydrate free gas trap sealed by the hydrates and normal fault (star).

Conclusions. All abovementioned illustrates geological complexity of hydrocarbon prospecting in the Black Sea and requires due adjustments to exploration targeting and comprehensive feasibility studies to attract long-term investments to develop its petroleum potential. Last decade the series of profound theses were published and shed the light on key problems of the Black Sea geology and petroleum potential [1, 4, 6, 7, 9, 10] though a lot of critical issues are still waiting correct answers and updates. To give an impetus to hydrocarbon exploration in the Black sea it seems a vital prerequisite to establish an exploration consortium of the geological state surveys and governmental agencies as well as national and international oil companies of the counties sharing and studying that promising but still underexplored marine basin.

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НОВЫЙ ЭТАП НЕФТЕГАЗОПОИСКОВЫХ РАБОТ В ЧЕРНОМОРСКОМ БАССЕЙНЕ: УТОЧНЕНИЕ ГЕОЛОГИЧЕСКОГО СТРОЕНИЯ И ПЕРСПЕКТИВ ОСВОЕНИЯ

Черноморский бассейн – один из последних недостаточно изученных, высокоперспективных и, одновремено, наиболее близких к Европейскому рынку нефтегазоносных регионов. Однако ряд объективных и субъективных факторов задерживают масштабное освоение нефтегазового потенциала Черного моря, в особенности углеводородных ресурсов глубоководной акватории, включая метаногидраты и подгидратные залежи свободного газа. Анализируются геологические риски освоения нефтегазового потенциала бассейна на основе анализа результатов новейших поисково-разведочных работ.

Ключевые слова: Черное море, поисково-разведочная скважина, термическая зрелость, углеводородные ресурсы, тектоническая эволюция, глубоководное осадконакопление, породы-коллекторы, газогидраты.

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НОВИЙ ЕТАП НАФТОГАЗОПОШУКОВИХ РОБІТ У ЧОРНОМОРСЬКОМУ БАСЕЙНІ: УТОЧНЕННЯ ГЕОЛОГІЧНОЇ БУДОВИ ТА ПЕРСПЕКТИВ ОСВОЄННЯ

Чорноморський басейн - один з останніх недостатньо вивчених, високоперспективних, і, водночас, найбільш наближених до Європейського ринку нафтогазоносних регіонів. Проте існує низка об'єктивних та суб'єктивних чинників, які стримують масштабне освоєння нафтогазового потенціалу Чорного моря, в особливості вуглеводневих ресурсів глибоководної акваторії, включно з метаногідратами та підгідратними покладами вільного газу. Аналізуються геологічні риски освоєння нафтогазового потенціалу басейну на основі аналізу результатів новітніх пошуково-розвідувальних робіт.
Ключові слова: Чорне море, пошуково-розвідувальна свердловина, термічна зрілість, вуглеводневі ресурси, тектонічна еволюція, глибоководна седиментація, породи-колектори, газогідрати.

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