Overturned Salt Roof Flaps in the Dnieper-Donets Basin – Hiding a New Giant?

Introduction

Dnieper-Donets basin (DDB) is a mature oil-and-gas region with over 200 hydrocarbon accumulations, many of which are associated with salt domes. The most proliferous of salt-associated oil and gas fields are found in the axial part of the depression at 4-5 km depth, while deeper near-salt succession is not studied.

Dnieper-Donets basin is a Late-Devonian rift, filled with pre- and syn-rift Devonian sequence and overlain with post-rift Carboniferous, Permian, Mezozoic and Cenozoic fill (Gregory F. Ulmishek, 2001; Stovba S. M., 2003). In the axial part of the basin Devonian salt penetrates over 10 km Carboniferous-Permian sequence. Majoir post-rift tectonic events took place between Devonian and Carboniferous, at the end of Early Visean, in the Middle of Serpukhovian, between Early and Middle Carboniferous, in Permian and between Mesozoic and Cenozoic times (Stovba S., 1996; Stovba S. M., 2003). Basin on seismic data observations salt flow is considered to start in Devonian with sedimentary overburden less than 300–400 meters, with post-rift phases of salt movements being related to the regional tectonic reactivation of the basin. The period between Bashkirian and earliest Permian was regarded to be characterised by the halokinetic quiescence (Stovba S. M., 2003).

New geophysical data evidence about possible reactivation of salt diapirism between Late-Moscovian and Early Carboniferous in the axial deep part of the basin, leading to formation of huge overturned flaps. The latter were interpreted as part of the salt diapir on seismic data due to noisy image. Proposed geological model show that absence of reflecting boundaries here may result from flaps' dip and partial destruction. High probability of mentioned salt reactivation is also supported by theoretical geomechanical models.

Method

The study presented was undertaken as a part of exploration program of two old hydrocarbon fields on the final stage of development, where oil and gas accumulations are associated with under-the-salt-wing blocks at 4-5 km depth. The task was to accurately delineate extension of the known deposits and to identify deeper ones. Taking into account presence of the salt dome investigated area was significantly increased to accurately map the shape of the salt diapir down to Devonian mother-salt.

High accuracy gravity survey was performed on the 100x100 meters net on the area of 408 sq.km, resulting accuracy of the complete Bouguer anomaly of 8.6 μGal. As an interpretation approach we used joint inversion of gravity, seismic, well log, production data with additional geological information (Petrovskyy. 2005). Introduction of gravity data to the interpretation process allowed for accurate mapping of the salt body and evidenced it to be smaller than by seismic data interpretation (Figure 2). Gravity misfit function resulted from the inversion (Figure 1) allowed to map small-amplitude linear elements, associated with the tectonic structure.

Study results

Strike and location of mapped linear elements relatively to the salt body, together with magnetic data, evidence these elements are not related to faults. Wells, drilled at the south-western flank of the salt diapir (Figure 3b) , penetrate uplifted blocks of different ages: from Serpukhovian to Moscovian, which were previously thought to be upturned flaps. Superposition of mapped linear elements and mentioned wells suggests existing of two flaps with reverse succession (younger rocks closer to the salt body) of Serpukhovian – Bashkirian – Moscovian sediments. One of the geological models allowing to explain observed double reverse succession is a model of overturned salt roof flaps, formed under the regional extension tectonic regime (Schultz-Ela, 1993; cited from (Martin P. A. Jackson and Michael R. Hudec, 2017), which dominated in the DDB until Cretaceous. Rotational forces cannot either be excluded as a

driving mechanism that have stacked two overturned blocks together. Wells drilled at the north-eastern flank of the salt body evidence existence of the uplifted Middle-Lower Carboniferous block with a straight succession of layers (older layers closer to the salt body) in immediate proximity to the salt diapir (Figure 3a), presumably followed by the overturned salt roof flap by analogy to the south-eastern flank.

Age of the overturned blocks suggests Late Moscovian-Upper Carboniferous salt reactivation. As no major regional tectonic events took place in the region at that time, we assume buoyancy and differential loading (under the regional extension) were driving mechanisms for salt movement. From the geomechanical positions high probability of such reactivation is caused by smaller thickness of the overburden needed to be brokenthrough by salt comparing to Permian reactivation after Bashkirian-Permian quiescence. 2D geological model of field–analogue, preserving sedimentary roof over the salt dome is illustrated on the Figure 3d. Here shallower depth, smaller thicknesses of booth overburden and salt prevented salt breakthrough. Faulting type here indicates postkinematic sedimentation of Serpukhovian – Moskovian as classified in (Martin P. A. Jackson and Michael R. Hudec, 2017).

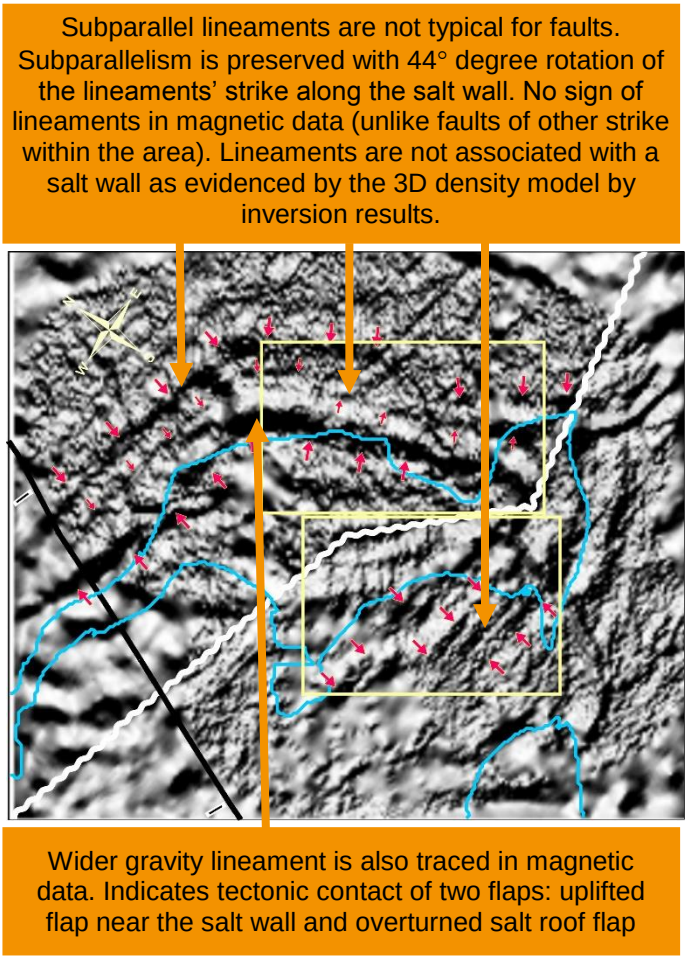

Figure 1 *Gravity misfit (difference between the modelled gravity and complete Bouguer anomaly), obtained in the result of the 3D gravity inversion over one of the largest salt domes in the DDB. Lineaments, associated with upturned and overturned flaps, are indicated by red arrows. Salt diapers by the 3D gravity inversion is shown by blue line. Yellow rectangles show maps' limits from the Figure 3.*

Conclusions

Proposed geological model gives a simple mechanism explaining complicated Middle-Lower Carboniferous rocks perturbation beside the salt dome. If confirmed by drilling, suggested geological model opens a new direction for oil and gas exploration around numerous salt domes in the axial part of the DDB. Considering a variety of hydrocarbon traps that can be associated with mapped overturned salt roof flaps, regional tectonic settings and intensive density anomalies in the inverted 3D density model, there is high probability of big to huge hydrocarbon accumulations to be associated with an identified overturned flaps.

References

Jackson, Martin P. A., and Hudec , Michael R. [2017] Salt Tectonics. Principles and Practice. Cambridge University Press.

Petrovskyy, O.P. [2005] Mathematical Model of Integral Interpretation of Geological and Geophysical Data. *Geophysical Journal*. **27**, 900-904 (in Russian).

Schultz-Ela, D. [1993] Mechanics of active salt diapirism. Tectonophysics. **228**, 275–312.

Ulmishek, Gregory F. [2001]. Petroleum Geo-logy and Resources of the Dnieper-Donets Basin, Ukraine

and Russia. *U.S. Geological SurveBulletin 2201-E*.

Stovba, S.M. [2003] Style and timing of salt tectonics in the Dniepr-Donets Basin (Ukraine): implications for triggering and driving mechanisms of salt movement in sedimentary basins. *Marine and Petroleum Geology*. **19**, 1169-1189.

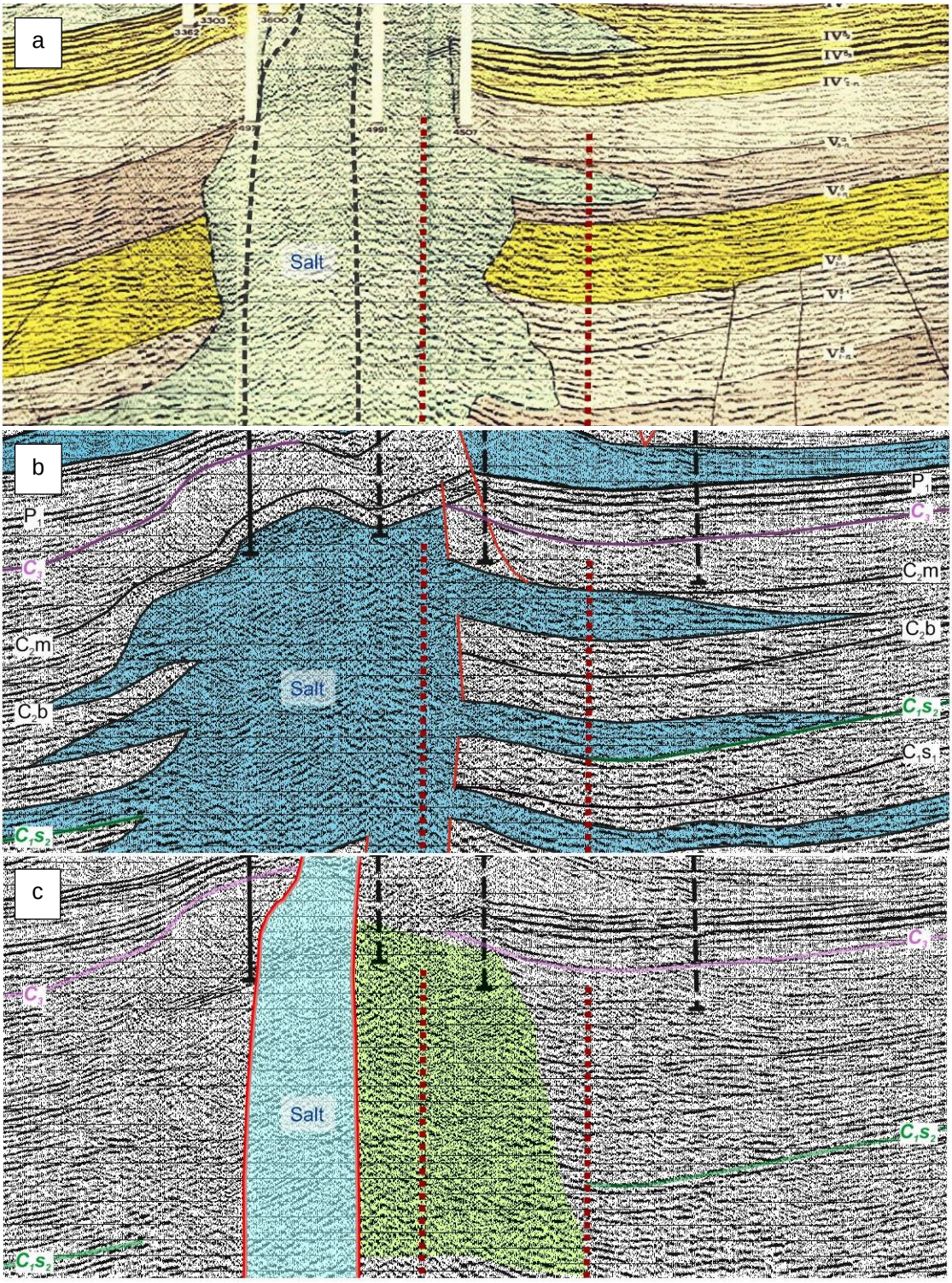

Figure 2 *Salt interpretation on regional seismic CDP 2D data by different authors (a and b). Salt by the 3D density modeling (c) overlaid over the same seismic image: dark red dashed lines limit the area of expected uplifted (closer to the salt wall) and overturned flaps; to the left from the salt dome high-precision gravity data were absent*

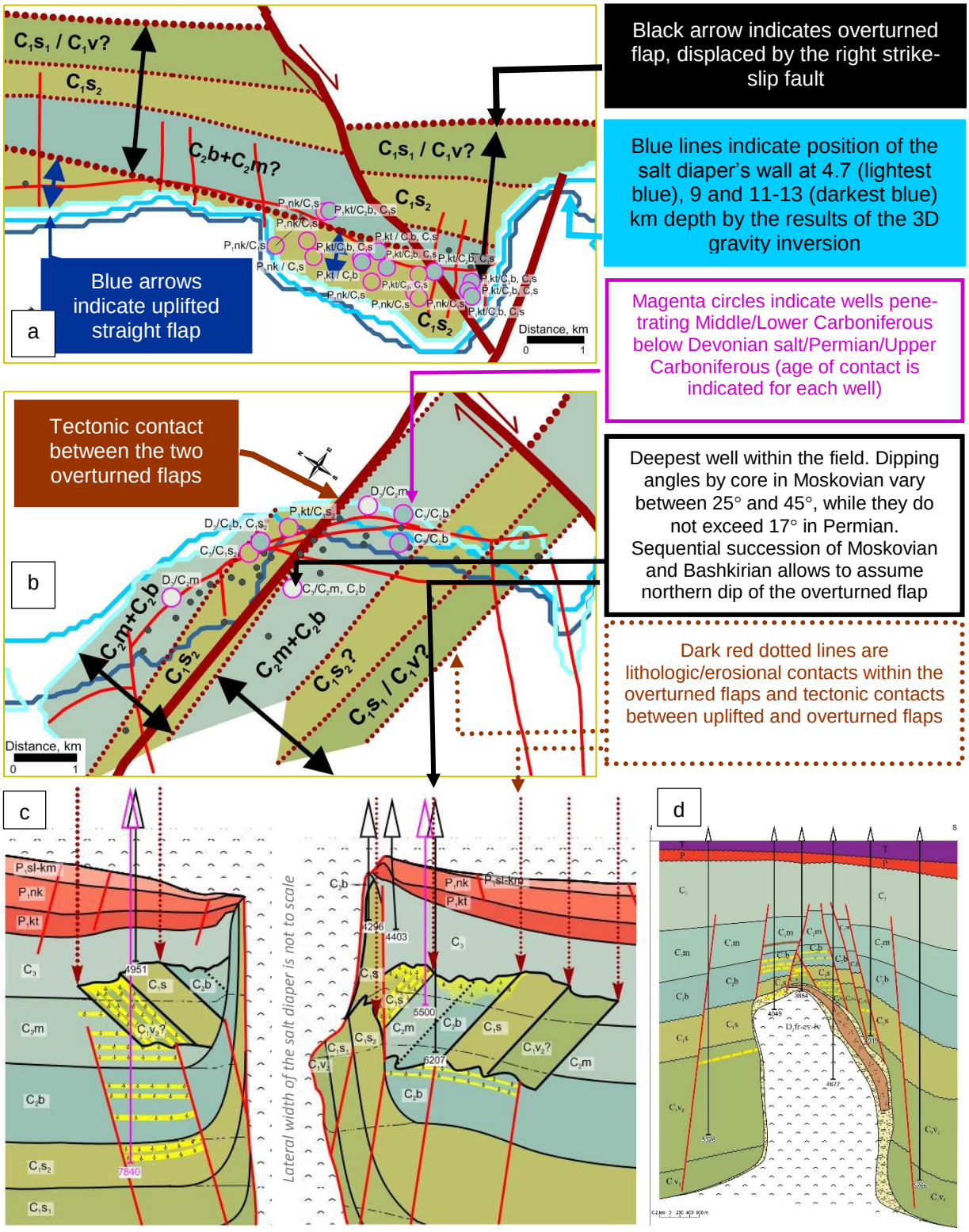

Figure 3 Conceptual model of the overturned salt roof flaps: a – at the north-eastern flank of the salt dome; b – at its south-western flank; c – conceptual cross-section. D – drilled analogue with preserved diapr's "roof" (modified from Lukin A. E., 2015), located at the axial part of the DDB basin at shallower depth. Faulting type in (d) indicates postkinematic sedimentation of the overburden.

Lukin, A. E., Goncharov, G. G. [2015] Plosive breccia as lithogeodynamical indicator of the initial stage of salt diapirism. *Geological Journal*. **353 (**4), 7-30.