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Pre-Salt Petroleum System of Vandji-Conkouati Structure (Lower Congo Basin), Republic of Congo

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Abstract: Lower Congo Basin located at the west central coastal part of Africa, which covers 115,000 km^2 out to water depths exceeding 3,500 m, presents Cretaceous pre and post-salt trend. The trend stretches to 350 km along the coastline at water depths <200 m from the Republic of Congo to central Angola. Conduits for oil migration generated from mature Pre-salt source rocks would be along fault planes and salt flanks. In this Basin, we distinguish the Vandji structure, which is the study case. And from the structure, reservoirs were highlighted by 3 wells: A, D and E. Well B and C show aquifers in Chela and Vandji Formations. Well D show aquifers in Chela and Vandji formations, but it shows some hydrocarbons in detrital intercalations included in Sialivakou Marls. In well E, Vandji formation is absent, probably eroded during the basement rising. The pre-salt petroleum system in Vandji-Conkouati structure, consists of two main separate reservoirs with oil accumulations (Jurassic basal sandstones of the Vandji formation) associated with gas caps (aptian Chela sands formation), a source-rock (Sialivakou marls), which act also as a cap-rock. The hydrocarbon migration is done along faults and Vandji and Chela formations. The trapping process could be caused by sealed faults.

Key words: Lower Congo Basin, vandji-conkouati structure, pre-salt petroleum system, chela, sialivakou marls, China

INTRODUCTION

Lower Congo Basin (West Africa passive margin) is characterized by predominantly Cretaceous sedimentary section with both pre-salt lacustrine and post-salt marine sediments recognized (water depths <200 m).

A thick section of marine-derived Aptian-aged salt, the loeme salt, subdivides the lacustrine section (informally known as the pre-salt) from the overlying marine (post-salt) section.

The pre-salt derived oil is able to migrate laterally and vertically into the post-salt reservoirs through holes or windows formed in the Loeme salt due to gravity sliding.

In the Lower Congo Basin, we can distinguish the Vandji-Conkouati structure, which is located at the northern part of the Congolese offshore.

Some of its reservoirs were highlighted by 3 wells: A, D, E. Well B is located at 6.8 km Northwest ward from well A and C at 2.3 km and well E at 2.5 km Northeast ward from well D. In this study, we will first give an overview of the geological settings of the Congolese Coastal Basin (lower Congo Basin) and then we will present the pre-salt petroleum system of the Vandji-Conkouati structure.

Geological settings of Congolese Coastal Basin

Regional geological history: The geological history of the congolese coastal basin started in early cretaceous (Neocomian) with a continental regime and ended in tertiary with marine regime.

In early cretaceous, a huge continent named Pangea was split up giving rise to the two continents actually known as South America and Africa that break up process corresponds to a rifting phase. According to Huc (2004), this separation process was initiated by the thinning and dislocation of a mainly granitic continental crust. The thinning was caused by the local uprise of partially melted igneous rocks coming from the underlying asthenosphere (Fig. 1).

The resulting rifts are occupied by large lakes such as the East Lakes actually observed in the East African Rift. Thick sediments rich in type-I organic matter were deposited in those lakes; then started the formation process of lacustrine source rocks.

The next process was an oceanic opening in which the asthenospheric magma began to be emplaced at the level of the mid-oceanic ridge, where it generates a basaltic oceanic crust making up the floor of the ocean being formed. This is the drift phase. As the ocean basin continues to open, the oldest parts of the oceanic crust,

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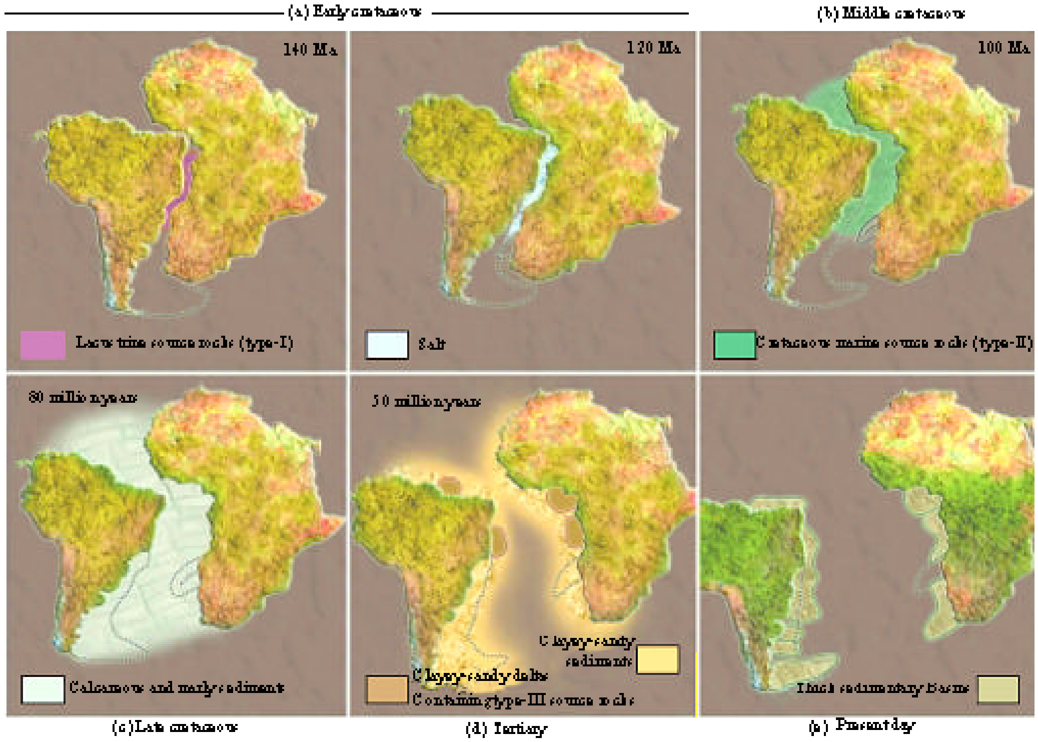

Fig. 1: a-e) Schematic evolution of coastal basin (Huc, 2004)

situated nearest to the continental margins, become progressively colder and their density increases, which leads to warping under the effect of their own weight. This corresponds to the phenomenon called downbending or flexure.

Thick terrigenous sedimentary sequences are accumulated in the space thus created at the end of the cretaceous, but especially during the tertiary. During that opening process, in Aptian, the created pathway has given way to an oceanic basin of irregular depth and moderate width. That basin was periodically isolated from the worldwide ocean; the phases of filling of this basin alternate with periods of isolation, during which the seawater are not replenished and then started an evaporation process resulting in the accumulation of large quantities of salt. Those salt layers covered the previously formed lake basins.

The confinement of the environment at that time has led to the regional deposition of sediments rich in type-2 organic matter able to act as source rocks. Despite the progressive increase of the basin width, its communication with the world ocean has continued to be limited. This confinement hinders the circulation as well as the oxygenation of water masses, which favors the accumulation of organic matter and the formation of type 2 source-rocks. During the late cretaceous, the opening has continued, so the ocean became ventilated, thus interrupting the conditions favorable for the accumulation of source rocks. The sediments were essentially composed of Marls. As Huc (2004) claimed at the end of the cretaceous that is around 80 Ma ago, the oceanic basin became sufficiently wide so it is ventilated by the circulation of marine waters containing dissolved oxygen.

In tertiary, thick layers of terrigenous sediments (clayey-sandy successions) fill the available space produced by the downbending of the margin. The deposits are thicker on the African side, because of greater intensity of erosion due to the uplift of the continent in response to its collision with the European continent. At this stage, type-3 source-rocks were deposited.

Those terrigenous sediments were accumulated as deltas. This depositional regime was favored by the cooling of the oceanic crust associated with the continental margins.

For Konyukhov (2008) in the Lower Congo Basin, the sedimentation was governed by movements related to the development of the East African rift system. The formation of carbonate and carbonate-clayey sediments prevailed here at early (Albian-Late Eocene) stages of the South Atlantic opening.

In source rocks, Total Organic Carbon (TOC) averages 2-3 weight % throughout the active rift siliclastic shale section, 6% in marls in the lower part of the late rift section and 1-2% in deltaic shales in the upper part of the late rift section (Harris *et al*., 2004).

Table 1: Summarized lithostratigraphic column of vandji-conkouati structure

Categories	Stages	Formations	Deposit environment	Paleogeography
Post-salt	Miocene	Paloukou	Littoral	Open sea
	Eocene	Madingo Marls	Marine	
	Paleovene			Oceanic basin
	Senonian	Emeraude siltstones	Margin-littoral	
	Turonian	Loango Dolomites	Littoral to continental	
	Cenomanian	Shally Siltstone of Likouala		Structures caused by salt tectonics and subsidence
	Albian	Sendji Carbonates	Littoral to coastal lagoon	Closed sea and salt tectonics
Salt	Aptien	Loeme Salt	Coastal lagoon	Saliferous lagoon with marine supplying
		Chela	Fluvial	
				Rifting
Pre-salt	Neocomian	Sialivakou Marls	Lacustrine	Blocks overturn movements Marked subsidence
		Vandji Sandstone	Fluvial	Beginning of extension
	Precambrian	Basement		

Stratigraphy and lithology: Stratigraphy and lithology are shown in the Table 1.

Pre-salt formations: The Vandji-Conkouati structure illustrates only Neocomian pre-salt formations. The Barremian pre-salt formations were eroded due to the rise of the basement.

Vandji sandstone (Neocomian): Quartzose sandstone light-gray, feldspathic and conglomeratic.

Sialivakou Marls (Neocomian): Claystone slightly micaceous dark gray to black, with interbedded sandstone.

Chela sand (Aptian; thickness: 15~60 m): It contains dark claystones with interbedded brown dolomites, to quartzose sands.

Salt formations (Aptian): It contains both sodic and potassic salts (Sylvinite).

Post-salt formations: In the post-salt formations Senonian and Turonian formations are missing.

Sendji carbonate (Albian): It contains whitish dolomitic limestones, white-gray dolomites, with interbedded quartzose sandstone, gray claystone.

Likouala shaly siltstone (late Albian, Cenomanian, Turonian): Quartzose sandstone, white to reddish, with interbedded brown claystone.

Loango dolomite (Turonian): Gritty (and often vuggy) dolomites, alternating with siltstones.

Madingo Marls (Senonian to Eocene): Gray dolomitic marls alternating with gritty and sometimes dolomitic, limestone and quartzose sand.

Paloukou Shaly sands (Miocene): Gray-brown dolomitic marls alternating with quartzose and clayey sand and with dark gray silty claystone.

Tectonics: In Coastal Congolese Basin, we have two tectonic processes:

- The first process is a breaking process which characterizes pre-salt formations and is related to the break up of the metamorphic basement (Fig. 2)
- The second process is a folding process located in the post-salt formations and related to salt tectonics

The Vandji-Conkouati structure displays an uprising of basement called Kaba high, which is elongate along N-S direction, paraleley to the horst of Noumbi located on the onshore part of the basin (Fig. 3). Between these two horsts, is located the Tchibota graben.

Pre-salt tectonics: The oceanic opening of the south Atlantic caused faulted blocks tectonic. We have two main regional tectonic stages:

- Late neocomian or pre-black marls (syn-rift 1)
- Late Barremian or pre-Chela (syn-rift 2)

When active rifting began in the early cretaceous, the pre-rift rocks in the central and Southern parts of the Congo Basin (referred as Lower Congo Basin) underwent extensive block faulting and erosion forming a graben-lacustrine depositional setting. The succeeding syn-rift rocks in the Congo Basin range from Neocomian to early Aptian in age and consist of lacustrine, alluvial and fluvial rocks (Brice *et al*., 1982; Da Costa *et al*., 2001).

Post-salt tectonics: Tectonics in post-salt formations is characterized by raft tectonics, which allows the extreme thin-skinned extension of overburden over a decollement of thin salt or other evaporates; Rafts are allochthonous fault blocks no longer in mutual contact (Duval *et al*., 1992).

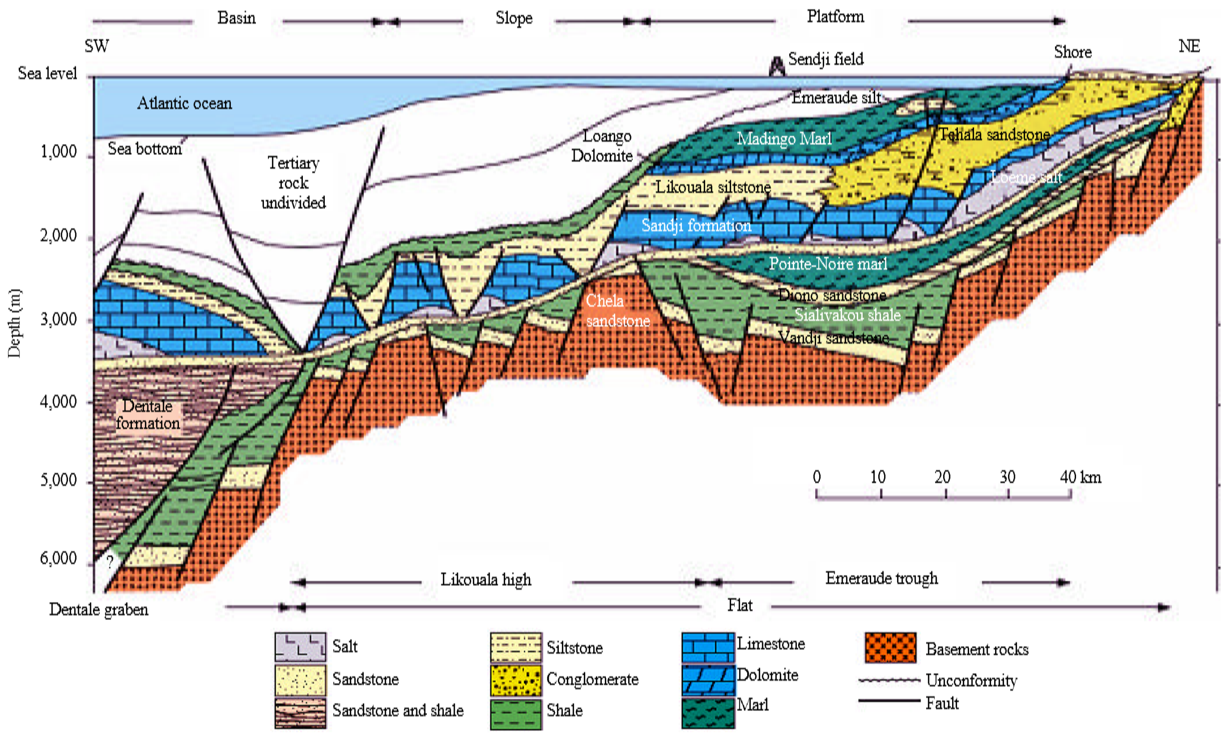

Fig. 2: Structural cross section (Brownfield and Charpentier, 2006; modified from Baudouy and Legorjus, 1991)

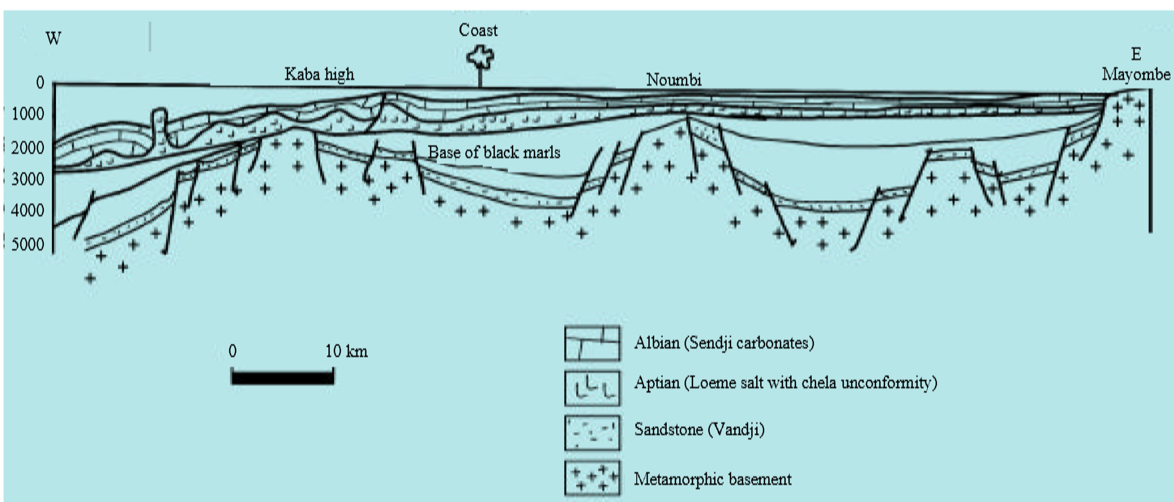

Fig. 3: Schematic structural cross section of the coastal section

In South Atlantic margin, the Lower Congo Basin contains the greatest salt-based fold thrust belt off Africa's Atlantic margin (Jackson *et al*., 2008). Besides, variations of Loeme evaporite thickness are a consequence of stratigraphic and structural control with salt instability influencing local variability. Because of that instability of the salt layer, the sedimentary cover on the continental slope is affected by important syn and post-sedimentary deformation due to gravity tectonics, which generated growth faults, salt sheets, diapir structures and compressional structures in response to substratum morphology of the basin and to the increase of sediment load (Savoye *et al*., 2009).

MATERIALS AND METHODS

The study of the Vandji-Conkouati structure is performed from the scale of the basin to the scale of the structure and it required the use of the following methods:

- Making a summarized overview of the geological settings of lower Congo Basin, from some related published studies
- Well test analysis and interpretation: in this step, from the analysis and interpretation of some well tests, we determine the type of fluids (gas, oil, or water) contained in the reservoir, its density and flow rate
- Drawing up gadama (well header, well pressure, reservoirproperties template…) and post-mortem (dry and discovery) files, by Microsoft office software (excel and powerpoint), in order to create reliable data bases and construction of summary charts for each of the wells analysed; files drawn up from well drilling final reports. Those files summarize some data such as: bottom hole temperature, pressure (hydrostatic), type of well tests, objectives and results of drilling, reservoirs reached (gross, net pay, net to gross)
- Drawing and updating some maps of Vandji structure, by CorelDraw graphics Suite 12 and Microsoft Office PowerPoint softwares.

RESULTS AND DISCUSSION

This oilfield is located in Congolese offshore, with around 20 m of water depth. Reservoirs were highlighted by well A, D and E (Fig. 4).

In Vandji-Conkouati structure, well A shows gas with condensates and oil, in Chela sands and Vandji sandstones. However, it is difficult to determine if these hydrocarbons have the same nature because of lack of data. Nevertheless, Chela formation contains oil, which is more lighter (oil density variation between 45 API and 75 API) than the oil contained in Vandji formation (around 40 API). In the drilling report summary, the bottom of the oil impregnated layer in Chela formation corresponds to the bottom of Chela formation; in the same formation, there is 2 m separation between the bottom of the gas impregnated layer and the top of the oil impregnated layer. Those 2 layers present porosity difference (gas layer 18%, oil layer 10%) and water saturation difference (gas layer 40%; oil layer 25%).

In Vandji sandstones formation, the separation between the bottom of gas impregnated layer and the top

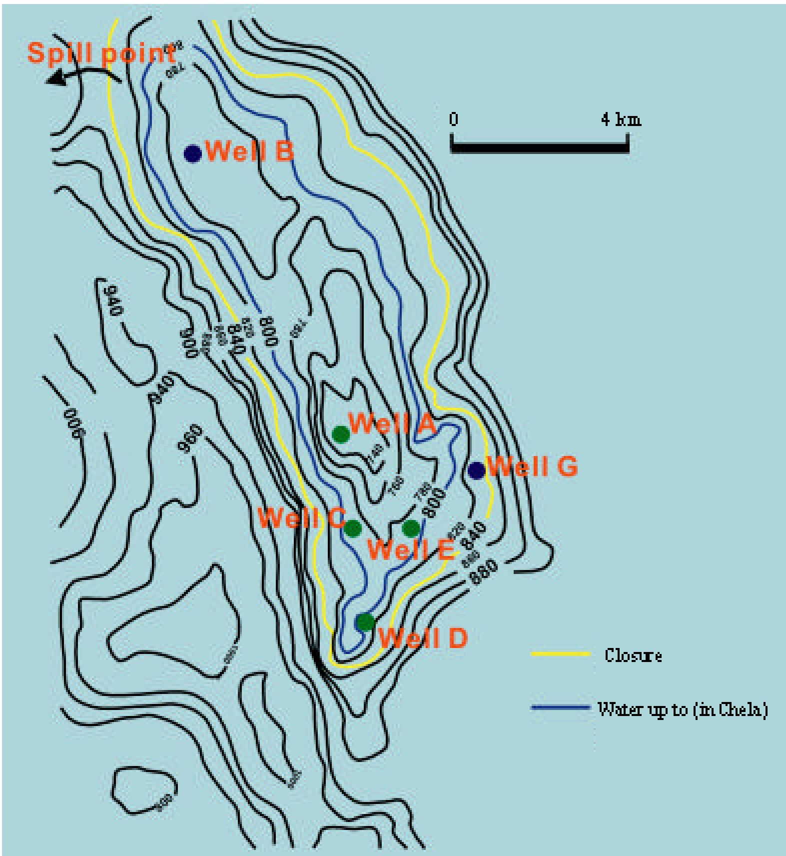

Fig. 4: Isochrones map: Bottom of salt (Vandji-Conkouati structure)

of oil impregnated layer is about 3 m. Nevertheless, well B and C display two aquifers: Chela and Vandji formations. Besides, well D also got to those aquifers, but it displays hydrocarbon in detrital layers included in Sialivakou marls, which is known as a source-rock; the Vandji formation is absent because the Sialivakou marls lay directly on the basement. In well E, the hydrocarbons contained in reservoir layers of Sialivakou marls extend to depth of 1489 m. In Chela formation, a probable water oil contact appears between 1374.5 and 1375.5 m and a gas oil contact at 1370.5 m.

The top of Chela formation in well D is estimated at 1422.5 m, whereas in well E the WOC is located between 1374.5 and 1375.5 m and then GOC is at 1370.5 m. Besides, the basement in well D is deeper than in well E. So, well E could be situated on a horst and well D and C in a graben.

Some normal faults are located between well D and A and between Well A and E. Those faults could play an important role in hydrocarbons trapping mode by their probable sealing properties. Between well D and A, Sialivakou Marls disappear; those marls were pinched out on a sort of horst, well E would be situated above that horst. The hypothetical cause of this pinch out, would be the erosion of the Sialivakou Marls due to Basement uprising.

CONCLUSION

The regional geology of Congolese Basin is characterized by two important transgressions: the Neocomian-Barremian transgression, which caused a mega sequence deposit in a lacustrine and restricted area, interrupted by an unconformity (Chela unconformity) which shows a peneplanation tectonic phase and the transgression from Aptian to Senonian deposits a mega sequence (in an opened area), which progressively developed from alluvial, fluvial and deltaic environment to an external shelf environment.

From the upper and senonian (Maastrichtian), started a regression which extended to quaternary. In the Vandji-Conkouati structure, the study is focused on presalt formations, aptian Chela sands formation and on Neocomian formations.

The petroleum system in Vandji-Conkouati structure, in its pre-salt area, consists of two main separate reservoirs with oil accumulations (Jurassic basal sandstones of the Vandji formation) associated with gas caps (Cretaceous Aptian sands of the Chela formation), a source-rock (Sialivakou Marls), which act also as a cap-rock. The hydrocarbon migration is along faults and Vandji and Chela formations.

The trapping process could be caused by sealed faults. In the Vandji structure, hydrocarbons are also contained in detrital layers included in Sialivakou Marls. Those detrital layers in Sialivakou Marls display hydrocarbons only in well D and E; so, it will not be easy to estimate their accumulation in the whole structure. Those two wells present an oil density around 38 API (in well D) and an oil density around 44.7 API (in well E).

But, because of lack of data, it is difficult to maintain that we have the same type of oil in these formations. We can not also maintain the distribution continuity of those hydrocarbons. Nevertheless, the probable sealing properties of faults (for example, between well D and E) could play a role in the trapping mode.

In the end, hydrocarbons were generated in the early cretaceous organic shales (Sialivakou Marls), which overlay the Vandji formation. Within that overlaying thick succession, occurs thin reservoir units (sandstone layers in Sialivakou Marls).

Exploration should be focused on the Chela formation, despite that it is known as a regional pipe. The explorationist geologist would look for some closure features of top-seal of Loeme salt, which could display probable traps. Then the Chela formation would be better suited for the production of gas.

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