REVIEW OF OIL DEPOSITS IN THE EAST BALTIC

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Over 40 oil deposits and shows are known in the mainland of the Baltic States and Kaliningrad Region. The oil-bearing formations are known from the Cambrian to the Permian. There are three most important levels among nine oil-bearing formations: the Deimena Formation (Middle Cambrian), the Volkhov Regional Stage (Lower Ordovician), and Pirgu and Porkuni regional stages (Upper Ordovician). Industrial oil pumping was started in 1975 in the Kaliningrad Region and in 1990 in Lithuania. Oil is produced only in mainland from the depths of 1600–2300 m. The deposit D–6 under the Baltic Sea, off the coast of Lithuania and the Kaliningrad Region has larger oil reserves than the mainland deposits.

In Latvia, small amounts of oil have been pumped at the Kuldiga deposit. The most perspective oil-bearing structure E–6 is located under the Baltic Sea.

In Estonia the possible areas of oil discovery could be in the Gulf of Riga, Irben Strait and at the western coast of Sõrve Peninsula.

Key words: Baltic States, Kaliningrad Region, Cambrian, Ordovician, Silurian, Devonian, bioherms, oil.

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INTRODUCTION

Over 40 oil deposits and shows are known in the Palaeozoic rocks in the mainland of the Baltic States and Kaliningrad Region of Russia. Undersea oil and gas deposits occur on the Baltic Shelf in Polish and Lithuanian territorial waters. The marginal areas of the Baltic Syneclise, including Estonia, have not been considered as possible oil deposits. At the same time, oil is pumped on Gotland Island located at the north-western border of the syneclise. Oil deposits are also known in its northern part (Lithuania) where they are related to carbonaceous bioherm complex.

GEOLOGICAL SETTING

The Baltic Syneclise is located in north-western part of the East European Platform, covering ca 200 000 km². Its eastern and north-eastern parts are located on the territory of Lithuania, Latvia and Estonia, its southern part embraces North-Western Poland and the Kaliningrad Region of Russia, and its western part extends on the Baltic Sea floor.

Crystalline basement of the syneclise is represented by Archaean and Proterozoic crystalline rocks. The latter are overlain by the Upper Proterozoic and Phanerozoic sedimentary rocks. The thickness of the sedimentary cover increases southwards, reaching 6–7 km in Northern Poland. Formation of the Baltic Syneclise began in the Early Cambrian, and was finished in the Upper Silurian.

In the platform sequence, four structural complexes are distinguished (Brangulis et al., 1993).

The Baikalian complex is represented by metamorphic and sedimentary rocks of the Vendian and Lower Ordovician age. These rocks are distributed sporadically in the eastern part of the syneclise, their thickness reaching 200–300 m.

The Caledonian complex occurs all over the area. It comprises terrigenous rocks of the Cambrian age, and carbonaceous and terrigenous-carbonaceous rocks of the Ordovician, Silurian and Devonian age. Thickness of the complex ranges from some hundreds of metres in the northern and eastern parts of the syneclise to 4000 m in its southern part.

The Hercynian complex occurs mainly in the central and southern parts of the syneclise. The thickness of the Devonian, Carboniferous and Permian terrigenous and carbonaceous-terrigenous rocks reaches 600–900 m.

The Alpine complex is distributed mainly in the southern part of the syneclise and is represented by the Upper Permian carbonaceous rocks and terrigenous rocks of the Triassic, Jurassic, Cretaceous and Paleogene. Thickness of the complex increases towards the south and southwest, reaching 1500 m on the territory of Poland.

Detailed stratigraphic correlation schemes of the sedimentary cover can be obtained from corresponding publications (Mens et al., 1990; Mens, 1992; Männil, Meidla, 1994; Nestor, 1993).

HISTORY OF OIL EXPLORATION IN THE EAST BALTIC

In the Baltic States, the signs of oil were first recorded in Estonia, where the oil-bearing Palaeozoic rocks lie close to the surface or crop out. The first reports about natural bitumens (NB), including descriptions of single shows of solid or viscous bitumens in Cambrian, Ordovician and Silurian sedimentary rocks, date back to the mid-19th century. Oil-like liquid was for the first time obtained from a well at Vaemla Manor (Hiiumaa Island) at a depth of 18 m in 1905. Oil prospecting was repeated in the same region during 1912–1924, but the results are not recorded. It has also been speculated that some workers may have faked the oil finds, by adding some oil to water in order to keep their well-paid jobs (Einpaul, 1961). However, new NB and oil shows recently discovered in Western Estonia proved this statement to be wrong (Kattai et al., 1992). The results of the oil-prospecting works early this century caused a kind of oil-fever in Estonia. From June 1 to November 30, 1922, 66 individuals and organizations submitted applications to the Estonian Government for obtaining oil exploration and pumping rights. However, there is no information about the investigations. Fifteen years later, intense emission of gas from a borehole drilled for oil prospecting was recorded on Prangli Island (Bartels, 1937), of the northern coast of Estonia.

In Central and Southern Baltic, the first oil shows were registered in 1949 in the Vilnius borehole in the Ordovician carbonaceous rocks (in fractures and caverns) at the depth of 226–230 m, and in 1957 in the South-Kaliningrad borehole in the Middle-Cambrian sandstones at the depth of 2351–2399 m (Sakalauskas, 1968).

Although theoretical preconditions and signs of oil-bearing characteristics of rocks were known in the Baltic area, the studies were started much later. The Lower Palaeozoic deposits were not considered as potential oil reservoirs, because all oil deposits at that time were known from the Meso- and Cenozoic rocks.

In the end of the 1950es, geophysical (gravimetrical, magnetometrical and seismological) investigations were started in Central and Southern Baltic. Detailed seismological works allowed to identify potential oil-bearing structures, where additional exploration boreholes were drilled. Regional geophysical investigations in the Baltic Sea began in 1963 (Sakalauskas, 1968). As yet, no seismological works for identification of oil-bearing structures have been carried out in Estonia.

Oil was first obtained from the Upper Ordovician rocks at the Kybartai deposit, Lithuania in 1962, at the Gussev deposit, Kaliningrad Region in 1963, and from the Kuldiga structure, Lithuania in 1964. The first deposits of economic value were discovered after 10 years prospecting works in the Kaliningrad Region and Lithuania: in 1966 Gargždai and Plunge, in 1968 Krasnyi Bor, Pietu and Šiupariai, in 1969 Ušakovo and Vilkyčiai, and in 1970 Laduškin deposit (Jaroščenko et al., 1976). During the following 15 years over 30 oil-bearing structures were discovered in the mainland of the Baltic States and also the first gas-oil deposits under the Baltic Sea in the sectors belonging to Poland and Lithuania (Vosylius, 1987).

OIL-BEARING LEVELS AND LOCALITIES

In the East Baltic area, oil shows are known from the Cambrian to the Permian. Up to nine oil-bearing strata have been distinguished, among which the three most important are the *Middle Cambrian Deimena Superformation ($\mathcal{C}_2$dm), the Lower Ordovician Volkhov Regional Stage (O_1vl) and the Upper Ordovician Pirgu and Porkuni regional stages (O_3prg – O_3pk).* Recently more interest has been paid to the Upper Silurian oil-bearing formations (Table 1).

The majority of *the Cambrian* oil-bearing formations and almost all oil deposits of economic value are related to the quartzose sandstones and siltstones of the Deimena Formation in western parts of Latvia and Lithuania (Figure). The depth of the oil-bearing beds is 500 m in the northern part (border area of the Baltic Syneclise), increasing southwards to up to 3000 m. The thickness of the Deimena Formation increases gradually towards the southeast, reaching 100 m, while its upper oil-bearing part increases from some metres up to 50 m (Laškova et al., 1976). The possibility of oil discovery increases in the same direction.

Industrial pumping of oil in the Kaliningrad Region was started at Krasnyi Bor, Ušakovo and Malinovo deposits in 1975. The oil yield ranges from some tons to 350 tons per day. The annual output increased from 0.29 to 0.95 million tons (Mt) in 1975–1977, and from 1.15 to 1.5 Mt in 1978–1992. Later the production decreased and the annual output was approximately 0.8 Mt in 1994. The total oil output of the Kaliningrad Region since 1975 exceeds 22 Mt.

In the mainland deposits, oil is produced only from the depths of 1900–2300 m, but the deposit D–6 under the Baltic Sea, not far from the border of Lithuania and the Kaliningrad Region, has estimated reserves of 10–25 Mt.

In Lithuania, oil pumping was started in 1990 and it is done in four deposits (Genčiai, Vilkyčiai, etc.). The oil yield of these deposits is 5–45 t/day and the depth of oil–bearing formations is 1600–2000 m. The annual output was 172 000 t in 1993, but in 1995 only 114 000 t was produced. The total output of oil in Lithuania since 1990 is estimated to be approximately 0.5 Mt.

In Latvia small amounts of oil have been pumped at the Kuldiga deposit at the depth less than 1000 m with maximum yield of 3.2 t/day. Currently, a prospective oil-bearing structure E–6 in the Baltic Sea has led to discussions between Latvia and Lithuania about its territorial belonging.

Ordovician and Silurian oil-bearing formations are considerably smaller than the Cambrian ones – both by yield and reserves (Table 2).

The second oil-bearing level is the Lower Ordovician Volkhov Regional Stage (O_1vl), where the oil-bearing formation is presented by thin (0.2–1.5 m) silt- or sandstone lenses in the upper section of the Kriukai Formation that is distributed on a limited territory (ca 3000 km²) in Western Latvia. Kuldiga, Vērgale and Liepaja oil-bearing formations are related to local uplifts, with the depth of the oil-bearing formation ranging from 900 to 1200 m.

Table 1

OIL-BEARING LAYERS OF THE BALTIC SYNECLISE

Series	British Series	*Shows* and **deposits**			
		Kaliningrad Region	Lithuania	Latvia	Baltic Sea
D_1		*Kulikovo*	*Gargždai* *Nida*	*Priekule*	*E-6*
S_2	Prīdolian Ludlowian	*Nesterov*	**Kudirkos-Naumiestis** **Lapgiriai** **Šaukenai** etc.		
S_1	Llandoverian (S_1jr-S_1rk)	*Gussev* *Krasnyi Bor*	*Kybartai* *Plunge*		
O_3	Ashgillian (O_3prg-O_3pk)	**Gussev**	*Kybartai* *Pajavone*	*Kuldiga* *Dubre* *Piltene* etc.	**Gotland**
O_{2-3}	Lower Ashgillian/ Upper Caradocian (O_2rk-O_{2-3}nb)	*Slavinsk* *Gussev*	*Kybartai* *Pajavone*		
O_2	Llandeilian (O_2uh-O_2kk)	*Gussev*	*Kybartai* *Pajavone*	*Kuldiga* *Edole* etc.	
O_1	Arenigian (O_1vl)			*Kuldiga* *Vērgalē* *Liepaja* etc.	
	Tremadocian (O_1pk)		**Šilalē**		
$Є_2$	($Є_2$dm)	**Krasnyi Bor** **Slavsk** **Ušakovo** **Išakovo** etc.	**Kybartai** **Genčiai** **Šiupariai** **Plunge** **Vilkyčiai** etc.	**Kuldiga**	*D-6* *E-6*

The oil yield reaches 1 t/day in the Kuldiga deposit and 150 l/day in the Liepaja deposit, being smaller in other deposits.

The third oil-bearing level is supposed to include the Middle Ordovician Uhaku and Kukruse regional stages (O_2uh–O_2kk). Extensive oil-bearing beds are not found here; oil forms impregnation splodges or occurs in pores, cavities and fractures of organogenic-detrital limestone. In several deposits e.g., Gussev, Kybartai, Pajavone, oil shows are found in the vaults of local uplifts. In the Kuldiga deposit, the oil yield reaches even 1.2 t/day. The possibility of oil discovery is supposed to be the border region of Kaliningrad Region and Lithuania where the supposable oil-bearing stratum lies a depth of 1200–1500 m and its thickness reaches 12 m.

The distribution area of oil shows related to the Rakvere and Nabala regional stages (O_2rk–O_{2-3}nb) almost coincides with that of the Uhaku-Kukruse regional stages and the frequency of oil shows in limestone in the Kybartai, Pajavone, Gussev and Slavinsk deposits is also close to that of previous oil-bearing level. The attempts to obtain oil by pumping have been unsuccessful.

By economic value, the second important oil-bearing level occurs in carbonaceous rocks of the Pirgu and Porkuni regional stages. The reef structures formed during the Pirgu time are of specific importance because they proved to be oil-bearing on Gotland Island, Sweden. On Gotland Island, more than 10 small deposits have been discovered, from which since 1972 oil has been obtained from the depth of 300–600 m. The average annual output is 1500–3500 t (maximum in 1980 – 30 000 t); the total production probably exceeds 100 000 t. In the result of joint investigations carried out by marine geologists from Latvia and Denmark, reef-like structures have been identified off the coast of Latvia, north-west of Ventspils, not far from Kurzeme (Figure). Considering the depth of occurrence of these structures, they are likely of the Late Ordovician age.

Another level of oil shows in the Upper Ordovician is related to the limestones of the Saldus Formation of the Porkuni Regional Stage. Two regions of possible oil discovery have been identified: near the eastern border of the Kaliningrad Region and in the Central Kurzeme. In the first-mentioned area, the Saldus Formation is represented by coarse-crystalline limestone with the admixture of sand; the thickness of the oil-bearing formation reaches 4 m and it lies at a depth of 1200–1600 m. Oil has been found in the Kybartai, Pajavone and Gussev

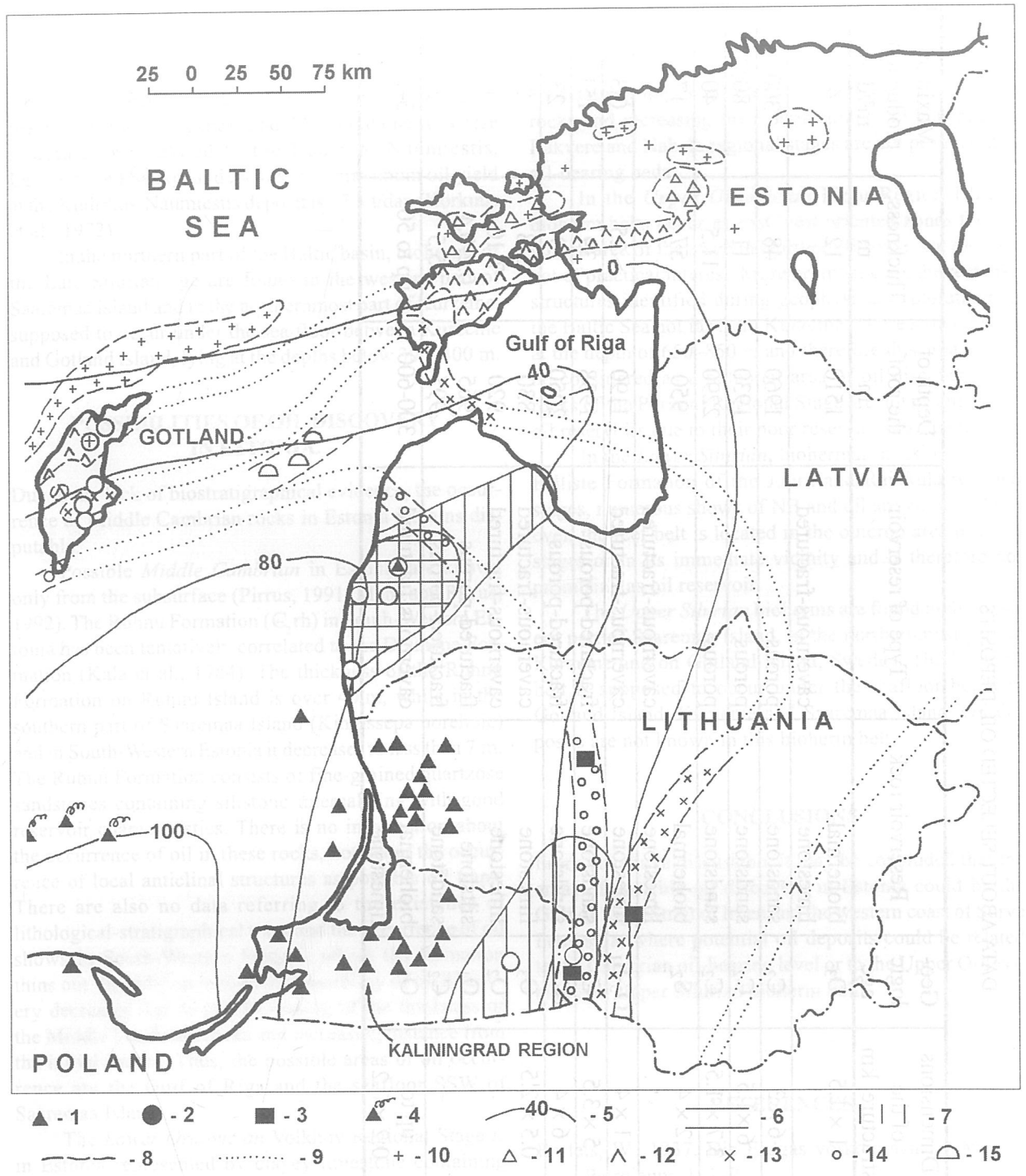

Figure. Distribution pattern of biohermal (reef) rocks, oil-bearing beds and oil deposits in the Baltic area (Kattai et al., 1995).
1-3 oil deposits: 1 – Cambrian, 2 – Ordovician, 3 – Silurian; 4 – gas deposits in Cambrian rocks, 5 – isopach of Deimena (Ruhnu) Formation (m); 6-7 areas of oil-bearing rocks: 6 – Volkhov, 7 – Pirgu-Porkuni; 8-15 areas of reef complexes: 8 – proved, 9 – supposed, 10 – Ordovician, 11 – Llandoverian, 12 – Wenlockian, 13 – Lower-Ludlowian, 14 – Upper-Ludlowian-Pridolian, 15 – unproved age.

deposits, with maximum oil yield 4 t/day in the Gussev deposit. In Kurzeme, the Saldus Formation consists of 3–6 m thick oolitic and sandy limestones lying at the depth of 800–1100 m. The shows that are not of industrial value are known from the Kuldiga, Piltene, Edole, Durbe deposits and elsewhere (Vosylius, 1987).

In the Lower Silurian, bioherms are widely distributed, but related oil deposits are not known. In Gotland Island and Estonia, zones of biohermal limestone are recorded on different stratigraphical levels. On Hiiumaa Island and Ridala Peninsula, numerous shows of NB are known from the Juuru and Raikküla regional stages (S_1jr-S_1rk). However, all of them occur either directly on the outcrop area or in its immediate vicinity and are therefore not promising as oil pools (Kattai et al., 1992; 1994).

More promising as oil-bearing structures are *the*

Table 2

DATA ABOUT SELECTED OIL DEPOSITS

Region	Deposit	Dimensions of the structure, km	Geo-logic age	Reservoir rock	Type of reservoir	Depth of the roof, m	Thickness, m	Maximum production, m^3/day
Kaliningrad Region	Gussev	1 × 1.5	O_3	biohermal limestone	cavernous-fractured	1510	12	4
	Krasnyi Bor	6 × 3	$Є_2$	sandstone	porous	1960	48	300
	Slavsk	6 ×1.5	$Є_2$	sandstone	porous	1930	11	80
	Gajev	3.7 × 1.5	$Є_2$	sandstone	porous	2290	11.5	40
Lithuania	Kudirkos-Naumiestis	2 × 4	S_2	biohermal limestone	cavernous-fractured	950	57	17
	Kybartai	1 × 4	O_3-S_1	limestone	cavernous-fractured	1190	> 25	0,3
	Vilkyčiai	5 × 3.5	$Є_2$	sandstone	fractured-porous	1938	39	151
	Vežaičiai	6 × 4	$Є_2$	sandstone	fractured-porous	2050	29	23
Latvia	Kuldiga	0.5 × 2.5	O_3	limestone	cavernous-fractured	830	5-8	?
			O_2	limestone	cavernous-fractured	920	7-10	1
			O_1	siltstone	fractured-porous	965	0.2-0.4	1
			$Є_2$	sandstone	fractured-porous	995	5.5	3
Sweden	Gotland	up to 0.2 × 0.2	O_3	biohermal limestone	cavernous-fractured	300-600	up to 50	3–5

Late-Silurian bioherms in Central Lithuania at the eastern border of the Baltic Syneclise, where they lie at the depth of 600–1200 m. The greatest possibilities of oil discovery are related to the largest, Early Prfdolian bioherms, reaching 57 m in thickness and 4 km in diametre. These structures are related to the Kudirkos-Naumiestis, Lapgiriai and Šaukenai deposits. The maximum oil yield at the Kudirkos-Naumiestis deposit is 17.3 t/day (Korkutis et al., 1972).

In the northern part of the Baltic basin, bioherms of the Late Silurian age are found in the western part of Saaremaa Island and in the northernmost part of Kurzeme, supposed to occur under the sea floor between Kurzeme and Gotland Island, lying at the depths below 300–400 m.

POSSIBILITIES OF OIL DISCOVERY IN ESTONIA.

Due to the lack of biostratigraphical evidence, the occurrence of Middle Cambrian rocks in Estonia remains disputable.

Possible *Middle Cambrian* in Estonia are known only from the subsurface (Pirrus, 1991; Mens and Pirrus, 1992). The Ruhnu Formation (C_2rh) in South-Western Estonia has been tentatively correlated to the Deimena Formation (Kala et al., 1984). The thickness of the Ruhnu Formation on Ruhnu Island is over 40 m, while in the southern part of Saaremaa Island (Kingissepa borehole) and in South-Western Estonia it decreases to less than 7 m. The Ruhnu Formation consists of fine-grained quartzose sandstones containing siltstone intercalating with good reservoir characteristics. There is no information about the occurrence of oil in these rocks, not about the occurrence of local anticlinal structures as possible oil traps. There are also no data referring to the existence of lithological-stratigraphical traps and the occurrence of oil shows in South-Western Estonia, where the formation thins out. In addition to that, the possibility of oil discovery decreases due to the decreasing of the thickness of the Middle Cambrian rocks and increasing distance from the initial source. Thus, the possible areas of oil occurrence are the Gulf of Riga and the seafloor SSW of Saaremaa Island.

The *Lower Ordovician* Volkhov Regional Stage is in Estonia represented by clayey limestone containing interlayers of marl with poor reservoir characteristics. Therefore the Volkhov Regional Stage appears not to be promising as possible oil-bearing rock.

The Middle Ordovician Uhaku and Kukruse Regional Stages are represented by limestones containing various amounts of clay and marl intercalations with poor reservoir characteristics. The shows of NB, analogous to the oil shows in Central and Southern Baltic are known from the northern part of Hiiumaa Island. As rocks with good reservoir characteristics are missing, the occurrence of hydrocarbons in these rocks is improbable.

The Rakvere and Nabala regional stages are represented by crypto- and microcrystalline limestone with thin interlcalations of marl which reservoir characteristics are poor. The shows of NB are known from the Kärdla crater area on Hiiumaa Island, where they occur at the depth of 50–60 m. In the neighbourhood of the impact structure during the Idavere time (O_2id) fracture zones were formed, considerably improving the reservoir characteristics of the rocks and increasing their permeability. In general, the Rakvere and Nabala regional stages are not promising as oil-bearing beds.

In the *Upper Ordovician* Pirgu Regional Stage bioherm belts occur as east-west oriented zones the exposure area of the stage in Northern Estonia, but they are not of practical interest. More promising are the reef-like structures identified during geophysical explorations in the Baltic Sea not far from Kurzeme. These structures lie at the depth of 650–850 m and therefore this area should be considered as a potential area of oil discovery. The rocks of the Porkuni Regional Stage are not promising as oil reservoirs due to their poor reservoir characteristics.

In the *Lower Silurian*, biohermal limestones of the Hilliste Formation of the Juuru and Raikküla regional stages, numerous shows of NB and oil are known. However, the reef belt is located in the outcrop area of these stages or in its immediate vicinity and is therefore not promising as oil reservoir.

The *Upper Silurian* bioherms are found in the western part of Saaremaa Island, in the northernmost part of Kurzeme and on Gotland Island, Sweden. The bioherm belt is supposed to occur under the seafloor between Gotland Island, Kurzeme and Saaremaa Island. Oil deposits are not known in this bioherm belt.

CONCLUSIONS

From the above discussion, it may be concluded that the areas of possible oil discovery in Estonia could be the Gulf of Riga, Strait of Irben and the western coast of Sõrve Peninsula, where potential oil deposits could be related to the Cambrian oil-bearing level or to the Upper Ordovician and Upper Silurian bioherm belts.

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