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Role of Deccan Trap in Hydrocarbon exploration in Kutch Offshore with special reference to thrust in Mesozoic Exploration

K.R.K. Singh*, M Singh and F. Dotiwala

Email:singh_krk@ongc.co.in

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Summary

Kutch offshore covering large area with sediments up to more than 10km at the depocenter has proved presence of commercial hydrocarbon in Tertiary and Mesozoic sequences. Number of wells has been drilled to explore either Tertiary or Tertiary and Mesozoic as dual objectives. Wells have been drilled mainly for the exploration and exploitation of Tertiary and Mesozoic sediments However, recent discoveries in Deccan Trap has opened up new play for exploration. Deccan Trap is overlain by Tertiary and underlay Mesozoic sediments.

An attempt has been made to bring out understanding about Thickness, Nature of lava flows, effect on drilling, and sub-basalt imaging for better geological understanding below Deccan Basalt and its bearing on exploration and exploitation of hydrocarbon in Kutch offshore.

Sesmic data acquired and interpreted has given good results for understanding Tertiary sediments. Number of discoveries has been made in Tertiary section and seismic data has been successfully helped to delineate the pool and structures. However few discoveries has been made in Mesozoic section and delineation of these discoveries and further mitigating uncertainities and risks are challenge. In recent past discoveries have been declared from Deccan trap where reservoirs are either weathered Basalt or Fractured Basalt. The testing in the wells from Basalt section were made based on hydrocarbon shows during drilling and other geophysical data. The thickness of Basalt in Kutch offshore varies from 0m to approx. 3000m.

Sub-basalt imaging not in Kutch offshore only but all over the world has been a challenge. However significant improvements in imaging of sub-basalt have been achieved in the recent years. This is mainly due to acquisition of 3D having spread length of 6Km and more. 2D Long offset data acquired with 12Km offset gave an insight into Mesozoic architecture in the area. Moreover, Pre Stack Time Migration and subsequent Beam Pre Stack Depth Migration 3D data processing involving gridded tomography, accurate velocity sampling has substantially contributed in improving sub-trappean imaging vis-à-vis conventional post stack data processing.

Understanding of petroleum system has been a great challenge as Tertiry-Tertiary, Mesozoic-Tertiary and Mesozoic-Mesozoic petroleum system were envisaged. The recent studies has brought out that Tertiary sediments are marginally mature to generate hydrocarbon. Thus only two petroleum system 1: Mesozoic-Mesozoic and 2: Mesozoic- Tertiary exists in Kutch offshore.

Significant improvement in drilling technology has been achieved in the recent past. This has led to successful completion of wells within shorter time. The drilling of Deccan Basalt is now not a big challenge. It has opened up new horizons for exploration.

Introduction

The Kutch basin is a pericratonic rift basin located on the Western margin of India (Fig:1). The evolution of the western continental margin basins of India is related to the breakup of eastern Gondwanaland from western Gondwanaland in the Late Triassic/Early Jurassic with N-S extension until the Early Cretaceous.

Fig. 1: Location Map

Rifting was dominantly along Dharwar trend in the offshore and along Delhi trend in the onshore leading to the formation of different fault blocks. Drifting of East and West Gondwana initiated in Middle Jurassic, with a component of anticlockwise rotation. Rifting along the west coast of India opened up the N-S striking Cambay Rift and the EW striking Narmada Rift/Surat Depression.

Madagascar began rifting from western India during the Middle Cretaceous (~ 90 Ma) along the NNW-SSE striking Dharwar trend (Gombos et al., 1995). India and the Seychelles continued to drift in the Late Cretaceous, and had completed 50° anticlockwise rotation (Biswas, 1982).

The Deccan/Reunion Hotspot activity in western India at ~ 66 Ma resulted in extensive Deccan flood basalt eruptions (Biswas, 1982; Courtillot et al., 1986) with varying thickness of 175m in NW and 2400 in the SE marking the Cretaceous-Tertiary boundary (Fig:2).

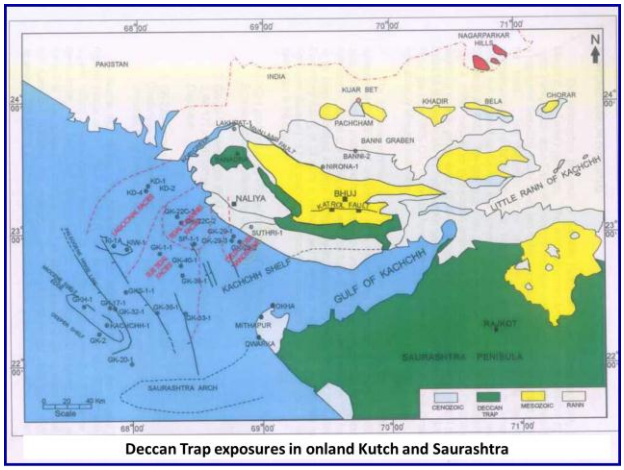

Fig. 2: Deccan Trap Exposures in Onland Kutch and saurashtra

The gentle folding of Mesozoic sediments in the Late Cretaceous with an angular unconformity can be related to the upliftment due to hot spot activity. Seychelles separated from mainland India at ~ 63 Ma, possibly in response to the weakened lithosphere in the vicinity of the mantle plume (Talwani and Gangopadhyay, 2001). Todal and Edholm (1998) suggest that the Laxmi Ridge, which is a marginal high,consisting of continental and oceanic crust, was created during the break-up between India and the Seychelles, but may have experienced later magmatic and/or tectonic deformation. As India moved off the hotspot, lithospheric cooling was accompanied by thermal subsidence and the formation of the Narmada Graben/Surat Depression (Biswas, 1982; Gombos et al., 1995).

Collision between India and Eurasia started in the Late Paleocene (~ 66 Ma; Jaeger et al.1989; Beck et al., 1995) which resulted in the re-activation of deep seated faults (NNW-SSE). Reverse movements have taken place along these faults giving rise to structuration throughout the basin. This late tectonics has over-ridden all earlier structuration in the area. Collision between India and Eurasia occurred by the Late Miocene, with the onshore Kutch Basin being subjected to ~ N-S compressive stress (Talwani and Gangopadhyay, 2001), with the development of folds and reverse faults.

Stratigraphy and Depositional Setting

The stratigraphy encountered in this area is given in the Table:1.

AGE	LITHOLOGY
RECENT to LATE MIOCENE	Clay, claystone with minor siltstone.
MID MIOCENE	Claystone with some limestone bands.
EARLY MOICENE	Limestone with minor claystone bands at bottom.
LATE to EARLY OLIGOCENE	Limestone with minor claystone and shale at places.
MIDDLE to LATE EOCENE	Limestone with very minor claystone and shale at places.
EARLY EOCENE	Mainly shale with some claystone in the upper part and siltstone bands with dominant shale towards bottom.
PALEOCENE	Mainly shale with few limestone bands
DECCAN TRAP	**Mainly greenish to dark greenish grey basaltic rocks.**
MESOZOIC	Mainly sandstone, siltstone and claystone intercalations with basic igneous intrusives at some places.

Table. 1: Age Vs Generic lithology in Kutch offshore area

The shelfal carbonates were deposited during Middle Jurassic time whereas the deltaic to transitional environment influenced the eastern part of the basin which is evidenced by the presence of arenaceous sequences in the wells Nirona-1 and Banni-1 drilled onland. The upper Jurassic period witnessed a regressive phase with a conspicuous shift in clastic lithofacies deposition further westward overlying the Middle Jurassic carbonate. The study of litho-facies from Kutch onland wells and Offshore wells reveals that Jhurio limestone of Middle Jurassic is overlain by clastic lithofacies of Jumara and Jhuran formations of upper Jurassic. The upper Jurassic clastics are composed of shales interspersed with fine and coarse grained sandstones. Drilling of offshore well AA-1 confirmed the presence of clastics in Upper Jurassic section.

The Early Cretaceous (Bhuj Formation) consists of huge thickness of non-marine sandstones deposited over the J-K unconformity. The inter-tonguing of marine rocks towards the sea indicates deltaic deposition under unstable sea levels. The Late Cretaceous sediments consist of mainly shelfal carbonates. However, the eastern part is covered with continental to shallow marine sandstones inter-bedded with thin basalt flows and shales. These Cretaceous sediments are overlain by Basalt flows.

Tertiary sediments over the basaltic cover are dominantly Paleocene–Eocene carbonate build-ups in a shelf margin set up. The possibility of having clastics in small lows over the Deccan basalt volcanics at Paleocene time cannot be ruled out. All the Tertiary sequences show drastic thinning with wedging out of older sequences towards east and southeast indicating that the Saurashtra arch remained high during the deposition of Tertiary sequences. The Mid Miocene and Post Mid Miocene witnessed huge clastic input which was eroded over the Saurashtra Arch showing truncation against recent sediments.

G&G STUDY

The Gravity and Magnetic data, regional 2D seismic data, high resolution 3D seismic data and all avaialble well data/correlation were utilized as an input to G&G study. Trap Top & Trap Bottom and Pay were mapped. Well logs were correlated ((Fig:3) and caliberated with seismic data.

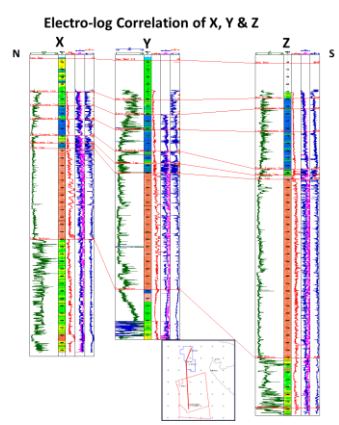

Fig. 3: Log Correlation along the along key wells.

Trap Bottom/Mesozoic Top: The Trap bottom, an unconformity was mapped (Fig: 4). Seismic reflection of Mesozoic can be seen truncating

against trap bottom, these sequences were identified either as sedimentary sequences or intrusive. Trap bottom was mapped with much difficulty as most of the seismic energy was consumed with in thick trap section.

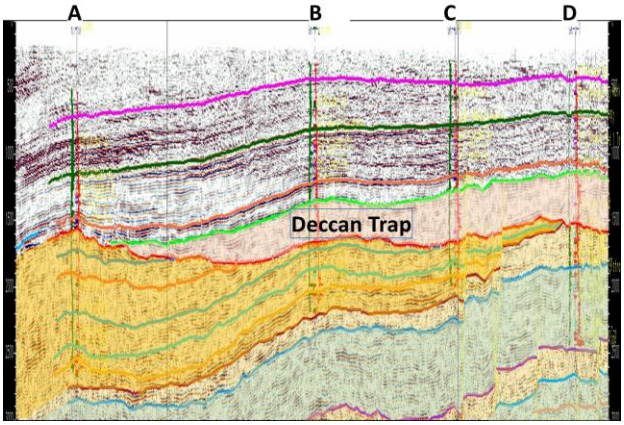

Fig. 4: Seismic section along the wells for Deccan Trap correlation and Mapping

Trap Thickness: The thickness of Basalt in Kutch offshore varies from 0m to approx. 3000m.The regional thickness of trap is following the trend of Trap top i.e. thickest portion of trap (>3000m) is present in the SW direction whereas thinnest portion is towards NE/SE(0m). Log correlation in N-S profile (Fig:5&6) and accordingly trap thickness map (Fig:7) was prepared. Gravity maps (Fig:8)prepared by KDMIPE was also used to understand the trap thickness regionally.

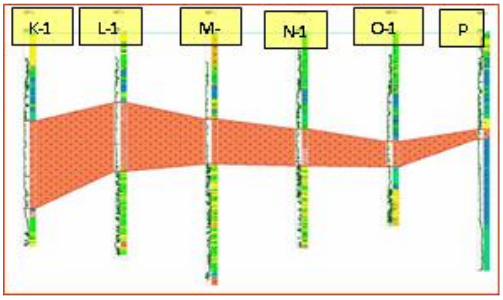

Fig. 5: Log correlation along the profile NE-SW onland well to offshore well

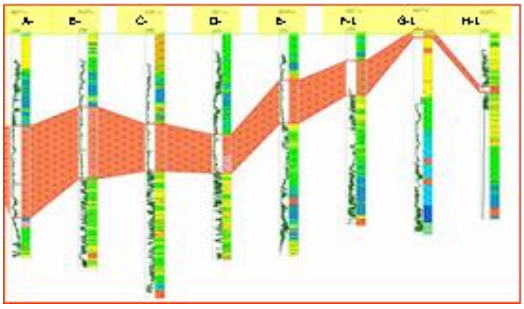

Fig. 6: Log correlation along the profileNE-SW onland well to offshore well

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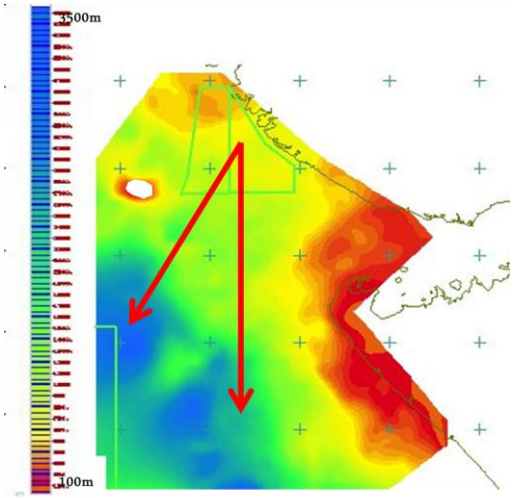

Fig. 7: Regional Time thickness map

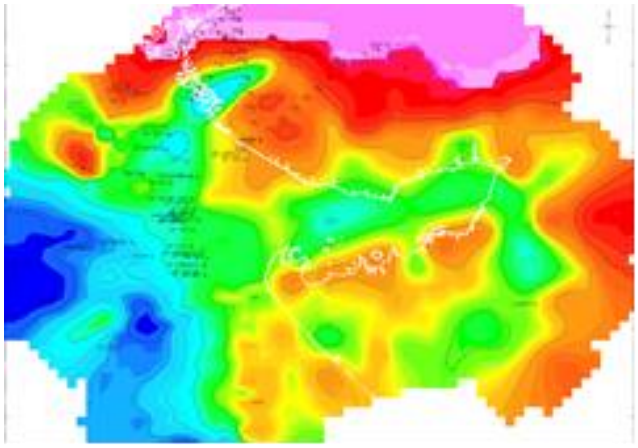

Fig. 8: Regional trap thickness map based on gravity data

Different flows (Fig:9) were recorded in the trap and weathering with varying range from 0 to 100% was also recorded.

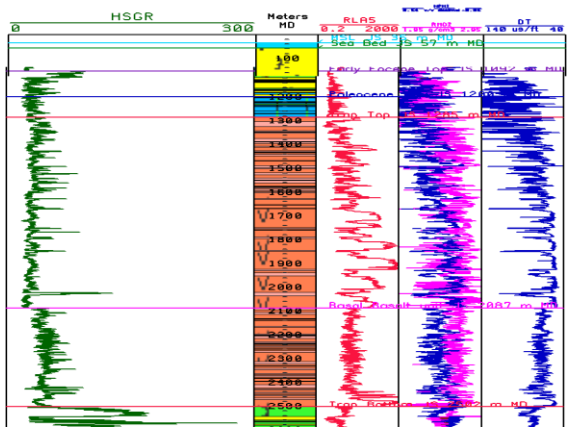

Fig. 9: Different flows within the basalt

Subsurface Imaging

Sub-basalt imaging not in Kutch offshore only but all over the world has been a challenge. However significant improvements in imaging of sub-basalt have been achieved in the recent years. This is mainly due to acquisition of 3D having spread length of 6Km and more. 2D Long offset data acquired with 12Km offset gave an insight into Mesozoic architecture in the area (Fig:10). Moreover, Pre Stack Time Migration and subsequent Beam Pre Stack Depth Migration 3D data processing involving gridded tomography, accurate velocity sampling has substantially contributed in improving sub-trappean imaging vis-à-vis conventional post stack data processing

The data of BLOCK-A acquired and processed for Pre stack Time Migration. Application of beam migration for better depiction of depth model is necessary for areal geological depth picture and understanding. The top and base of basalt layer as well as two reflectors within the Mesozoic could be mapped with reasonable confidence(Fig:11).The preservation of various physical attributes like amplitude, frequency and phase in PSTM processed data improved the mappability of sub-trappean strata

The facies variations and structural disposition in the western part of the study area could reasonably be evaluated through attribute studies. However, the evaluation was difficult in the eastern part probably due to poor alignment of events below Deccan Trap. The PSTM volume has brought out the anomaly at pay level and its extension as compared to the post stack data, this lead encourages for further exploration in the area.

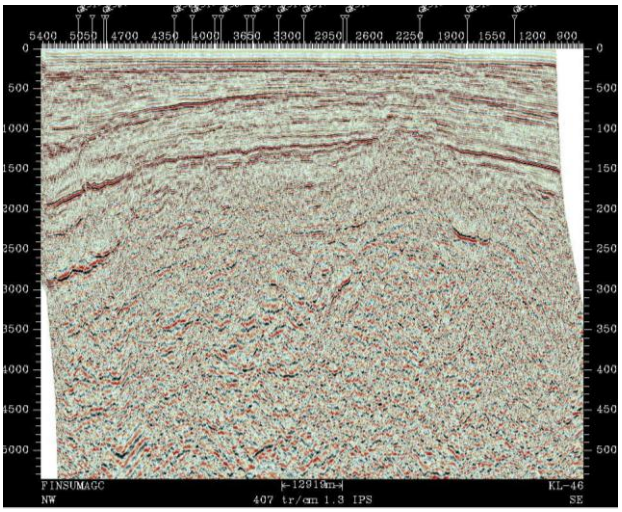

Fig. 10: 2D Seismic line

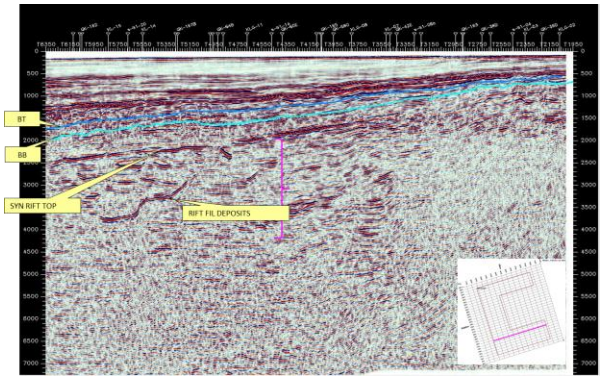

Fig. 11: 3D Seismic line

The process of updation of velocity model incorporating well data starts from the data preconditioning stage, which is taken up as Reprocessing with complete processing exercise. In complex geological setup/scenario, reprocessing is necessary for several times to come to a conclusion/understanding with additional information whatever is available.

PETROLEUM SYSTEM

In Pakistan Tertiry-Tertiary, Mesozoic-Tertiary and Mesozoic-Mesozoic petroleum system has been established. However the recent studies has brought out that Tertiary sediments in Kutch offshore are marginally mature to generate hydrocarbon. The Tertiary-Tertairy petroleum system is expected to be present in the areas where more tertary thicknesses are envisaged to reach the maturity for the source rock. Thus only two petroleum system 1: Mesozoic-Mesozoic and 2: Mesozoic- Tertiary dominantly exists in Kutch offshore. However following results has been obtained from the RGL Panvel:

1. The gases are thermogenic in origin indicating the presence of oil pools.
2. Oil/Gas generated are from Lr Cretaceous or Older
3. Tertiary source are not Mature enough to generate HC.
4. The maturity of oils is about VRc 0.7%. But oils of lower maturity is yet to be found.
5. Temperature gradient 30°C/1000m – maturity of sediments >2600m (Mesozoics).
6. CO_2 present is from Thermal degradation of OM (3-8%).

7. Presence of 8-14% Nitrogen in the gas may be due to mantle outgassing.

8. Shallow reservoirs (Mid Miocene) are charged with more matured gas than the Deeper reservoir (Early Eocene and Deeper).

9. Oil to Oil Correlation suggests the oils are derived from source rock deposited in sub anoxic conditions and are from three different groups

10. Paleocene & Early Eocene sediments possess potential source rocks of varying thickness from 40 to 160m & ~45m respectively.

11. Cretaceous sediments studied possess effective source rock.

12. Time of generation ~30mya – (Paleocene, Early Eocene reservoirs)

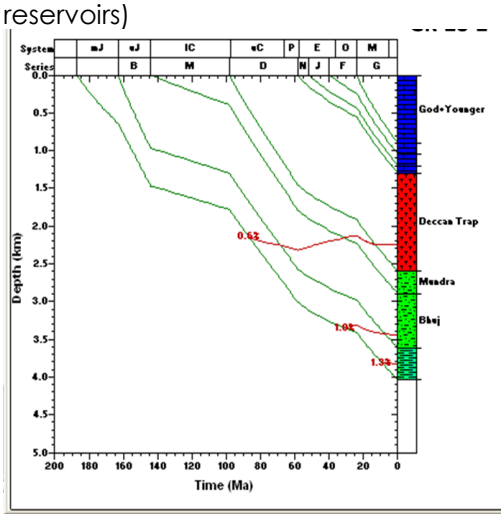

Fig. 12: Burial History of Well-A

Trapping Mechanism

The re-activation of deep seated faults (NNW-SSE) and reverse movements taken along these faults gave rise to structuration throughout the basin. This late tectonics has over-ridden all earlier structuration in the area. Collision between India and Eurasia occurred by the Late Miocene, with the onshore Kutch Basin being subjected to ~ N-S compressive stress with the development of folds and reverse faults. Enechelon faults joining together in NNW-SSE direction and forming strike slip faults has been observed. The reverse movements along these faults has also been identified.

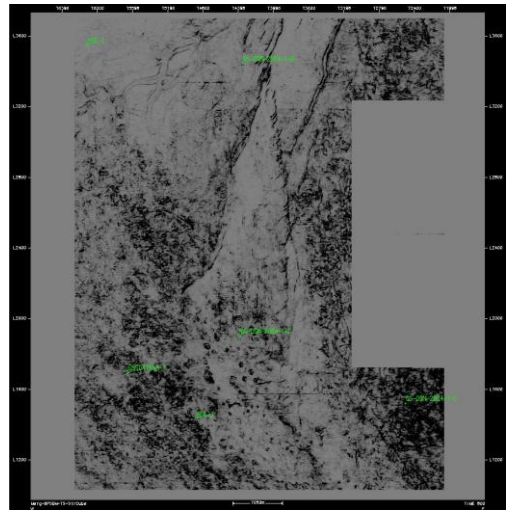

Fig. 13: Structure cube slice and Fault interpretation on 3D seismic data

Efficiency in drilling technology

Significant improvement in drilling technology has been achieved in the recent past. This has led to successful completion of wells within shorter time. The drilling of Deccan Basalt is now not a big challenge. It has opened up new horizons for exploration

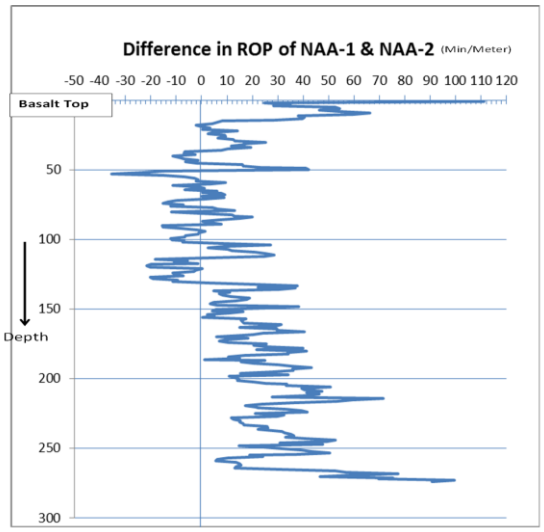

Fig. 14: Difference in ROP of two well drilled with different types of bits

Conclusion:

Recent discoveries in Deccan Trap has opened up new play for exploration. Geological understanding of Deccan Basalt and below has bearing on exploration and exploitation. Discoveries declared from Deccan trap are either from weathered Basalt or Fractured Basalt.

The thickness of basalt ranges from 0m in the North to 3000m in South. Sesmic data acquired and interpreted has given good results for understanding Tertiary sediments. Significant improvements in imaging of sub-basalt have been achieved in the recent years. Recent studies has brought out that Tertiary sediments as marginally mature to generate hydrocarbon and only two petroleum system 1: Mesozoic-Mesozoic and 2: Mesozoic- Tertiary exists in Kutch offshore.

Significant improvement in drilling technology has been achieved in the recent past. Thus drilling of Deccan trap is no more a big problem.

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