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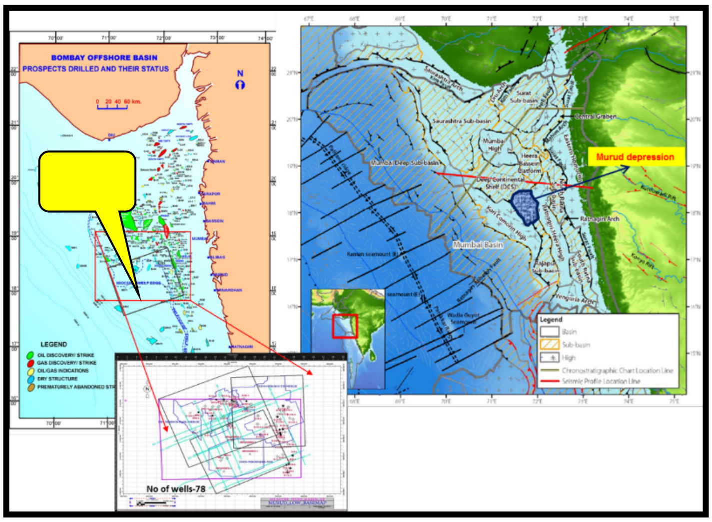
A possible Post- Mid Miocene meteoritic impact at Murud Depression, Mumbai Offshore Basin, India

Abstract:

Being one of the least explored area of western offshore basin, a R&D project was carried out in Murud Depression area of Western Offshore Basin, India to bring out a best possible geological model in this part of basin. Area of interest (AOI) encompasses Murud Depression, Mumbai high, HPB, DCS sector and NW-Mukta for regional understanding. In Murud Depression six wells have been drilled so far without any commercial success. In spite of this, the presence of hydrocarbon cannot be ruled out, as indication of feeble gas was observed during production testing within Eocene. The source rock analysis also indicates potential source rock occurrence in the area. The present study has brought out that the Murud Depression has witnessed a catastrophic meteor impact during the post Mid-Miocene time (after deposition of LII) which has severely influenced the hydrocarbon distribution and altered the structural style observed in Murud Depression, BHDCS and HPB sectors. The radial fault pattern emerging from the centre of impact in Murud Depression appears to have affected the adjoining areas. Exclusive circular to semi-circular concentric fault pattern in the central part of Murud, its close resemblance to a complex crater, ultra high temperature (causing failure of drilling/ logging tool and overmaturation of source rock) encountered during drilling, L-II pack thickening due to shale squeezing adjacent to central faulted part, huge deposition of post L-II reflection free clay fills, reactivation of some of the older rift phase fault after L-II, discrete charging of shallower Ratnagiri and Panvel formation, non-occurrence of hydrocarbon in deeper Bassein and Mukta formation in NBP field as well as low energy low GOR oil due to breaching of earlier pools, enormous amount of Hydrocarbon occurrence in L-III (almost one third of total reserves of Mumbai Offshore Basin) as a consequence of dismigration, all points towards a post-mid Miocene meteoritic impact in Murud Depression. The intense shock waves generated during impact would have resulted in extensive fracturing and brecciation of older carbonates rocks resulting in carbonate breccia and fractured reservoirs. In spite of, no carbonate breccia reservoirs have been established, fractured Basement reservoirs as encountered in MH and Heera fields also would have been impacted by this impact event.

INTRODUCTION



Murud Depression area falls in NELP-VII MB-OSN-2005/5 & 6 block of Western offshore Basin, India. The block is situated in SSE of the Mumbai high DCS platform and about 26 kms west of the Heera field & southeast of D-18 field (Figure.1). A transverse ridge along SM-67 structure separates Murud Depression from the Rajapur low in the south (Lal, N.K. 1995). The Srivardhan horst or Ratnagiri-Heera High occurs to the east, separated from the Murud Sub-basin by the Ratnagiri Shelf Fault, whilst the Kori Comorin High forms the western margin. The area is situated within a bathymetric range of 70-110m. Despite its relatively small size, the Murud Sub-basin is indicated as having a sedimentary fill up to 7,500m by Zutshi and Panwar (1997). Structurally Murud Depression is dominated by three principal fault types, viz., (a) rift phase – Basement involved extensional faults, (b) syn-depositional listric faults & (c) reactivated NNE-SSW trending Middle Miocene faults. The sedimentation in the area started with rifting in Bombay offshore basin in Late Cretaceous-Early Paleocene time. The end of the rift phase is marked by a major Early Eocene unconformity represented by a prominent seismic marker H4. This unconformity marks the boundary between two different structural styles, viz., syn-rift and post-rift. The post-rift deposition in the Depression was controlled by a most probable meteorite impact, gravitational processes and eustatic sea-level changes. The seismic marker H3CGG, corresponding to Late Oligocene, which is a regional unconformity is not traceable in major part of this block due to facies change and large degree of deformation across the shelf break. By the Oligocene time, most of the rift related faults become inactive. Six wells (Well-1, Well-2, Well-3, Well-4, Well-5 and Well-6) had been drilled in Murud Depression area with no commercial success so far. Well-1 drilled down to Bassein (H3B), Well -2 down to L-II, Well-3 down to L-II, Well-4, Well-5 and Well-6 drilled down to Devgarh (H4). None of the six wells have penetrated basement. Source rock analysis data of Well-1 in this block depicts that Middle Eocene to Early Oligocene section represents Type-III Kerogen with mature organic matter. This zone can be termed as fair in respect of hydrocarbon generation potential which might have generated oil & gas. This zone falls under oil window. In the Well-4, a cumulative 235 m thick source rock within the Paleocene to early Eocene in the depth interval of 4770-5010m exhibits fair organic richness (avg TOC

1.6%) and residual potential (avg. S2 4.6 mg/ g rock). The remaining organic matter is found to be of type III/II. Below 4900 m, source rock identified in this well is in the wet gas zone. In the Well-5 a cumulative 140m of effective source (4910-5050m) with fair organic richness (avg. TOC 1.1%) is encountered and remaining organic matter is found to be type II/I. Below 4200 m, the effective source rocks identified are in dry gas zone. Source rock in this well is in dry gas zone. In spite of the source potential identified in the wells, since none of the wells penetrate the deeper sequence within Lower Panna or Basement, hydrocarbon generation potential of Murud Depression still remains to be fully ascertained.

6. Model building

After doing stratigraphic correlation of about 78 wells, correlation and mapping of six major sequence boundaries was done (Figure.2). Then a combination of different methods (coherency (ESP), Structure cube, Discontinuity, Dip Azimuth etc) for fault detection was used to infer and map major and minor fault trends in
Murud area. Structure cube has been generated which clearly depicts the complicated fault geometry in the area (Figure.3). Fault pattern was very conspicuous on L-II (Mid Miocene) (Figure.3e and f) as well as on H3B (Early Eocene) (Figure.3 c and d) reflectors. In Murud Depression area faults appear to be concentric circular to semi-circular formed in a terrace zone of meteorite impact crater. Regional discontinuity/ coherency time slice at 1500 ms (Figure.4) showed faults are radiating towards adjacent area from the Central highly faulted part of Murud area.

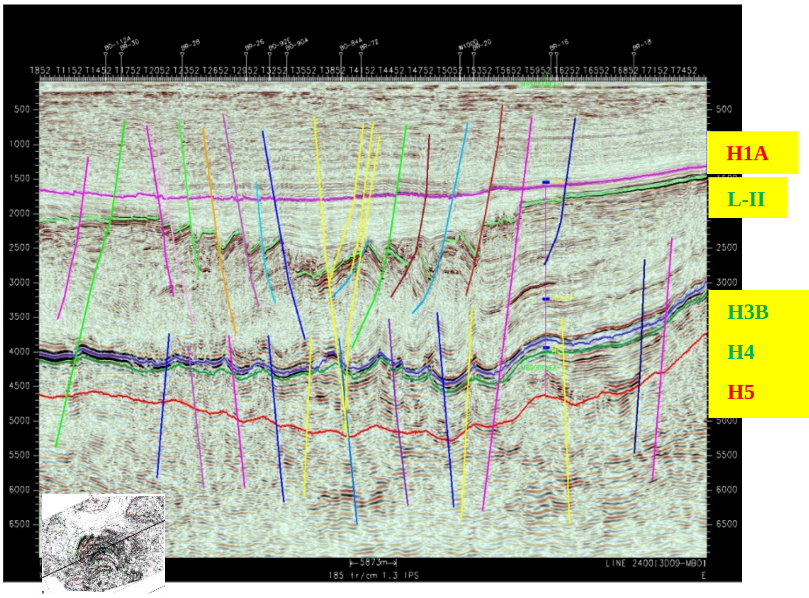


Figure.2: Seismic section along IL-2400 showing correlated horizons and faults inMurud Depression area

To understand the structural trends, time structure maps corresponding to correlated horizon (H5, H4 H3B, L-II, H1A and Water Bottom) were generated.

Figure.3: Time slices (TS) at different time extraxted from Structure cube volume showing fault pattern. a and b:Uninterpreted and interpreted TS at 4800 ms (correspond to H5); c and d: Uninterpreted and interpreted TS at 4100 ms (correspond to H3B) and e and f: Uninterpreted and interpreted TS at 2700 ms (corresponding to L-II)

Figure.4: Reg

Palinspastic structural restoration brought out that a post mid-miocene (after deposition of L-II) event triggered extensive listric faulting at L-II and reactivated some rift phase older faults which got ceased at Early Oligocene age. From this restoration following inferences were drawn:

- Murud Depression was a paleo-low and was formed during Late Cretaceous/Early Paleocene time. The older faults are manifestation of basement tectonics developed during rifting stage.
- The central portion of Murud Depression attained its peak development by Mid Miocene time. This is also evident from the maximum thickness observed within the central portion of Murud Depression in the restored section at LII level. The younger Mid Miocene faults were not active during the deposition of LII as demonstrated during restored section of L-II.

Evidences for possible impact

All the possible evidences were extracted from the available data to have a viable geological model for Murud Depression area. Most of the evidences point towards a possible post Mid Miocene extraterrestrial meteoritic impact in the Murud Depression area. This impact brought about a drastic change in the structural styling and distribution of hydrocarbon in this part of Western Offshore Basin. All the possible evidences analyzed during the current project are discussed in the following sections.

(i) Reflection pattern:

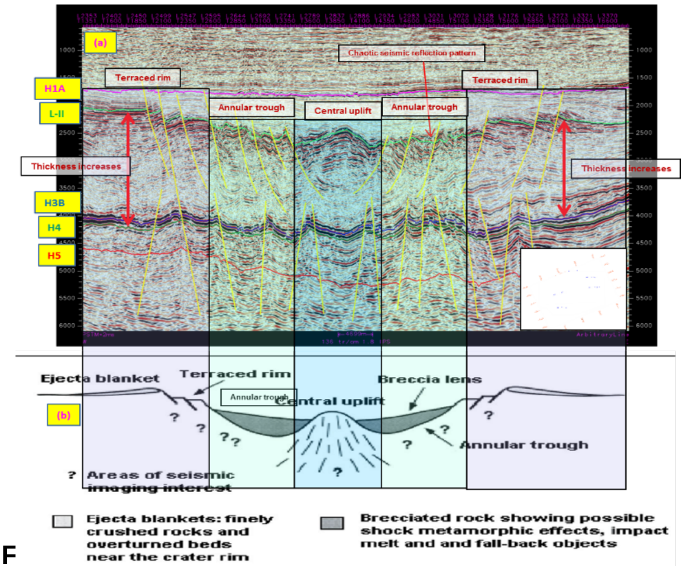


Figure ... -section of impact crater (

Seismic sections along IL-2400 (Figure.2) and arbitrary line (Figure.5) are primarily showing the two high reflectivity stratigraphic zone separated by transparent reflectivity zone. Shallower high reflectivity stratigraphy (Close to L-II) is highly faulted with highly dipping strata. Most of these faults are not propagating in upper strata. It can be inferred that this shallower strata got faulted after the deposition of this zone with subsequent subsidence. Seismic section also reveals a bowl shaped sagged cavity, uplifted and jagged rim part, highly faulted terrace rim. Chaotic seismic reflection just adjacent to L-II reflector indicates shattered portion of the impact causing lithological changes of breccia infill. Thickness of two high reflectivity zones reduced in the middle part and increased on both sides. This may be due to sudden pressure rise over the underneath sediments being squeezed out. Long term subsidence is very common in large scale impact structure (Tsikalas F. and Faleide J.I., 2007).

On the time slice of Structure cube at 2700 ms (close to L-II) faults are showing circular concentric pattern (Figure.3 e and f). The sagging structure of the shallower stratigraphy is later on filled by the homogeneous low reflectivity stratigraphy. Figure.5(after Westbroek and Stewart, 1995) summarizes the characteristic features in a complex crater, including normal faults and slumped blocks in the rim, breccia deposits and a well-developed central peak with upturned layers. Seismic section along an arbitrary line resembles like that of the complex crater (Figure.5a and b). All the Characteristics such as uplifted raised rims, fault bounded sagged annular synforms, highly faulted margin or terraced regions, breccia infill, and squeezing of material resulting in thickness reduction, points towards a possible impact incurred after deposition of L-II (Mid-Miocene).

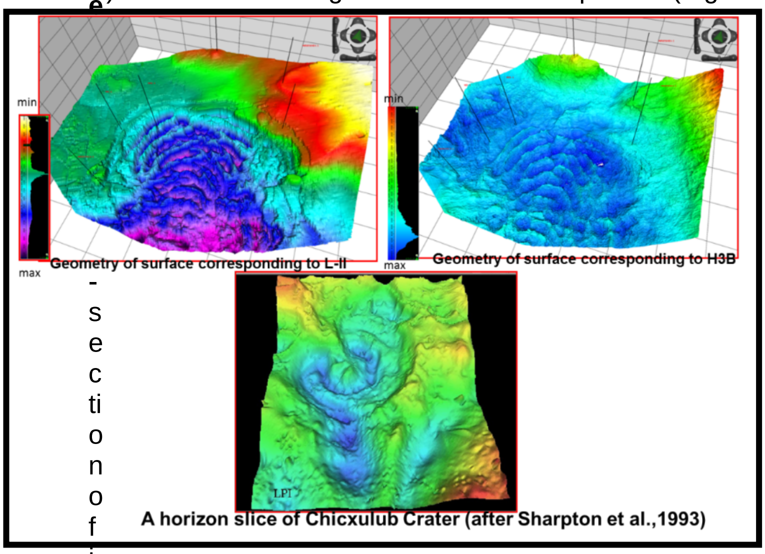


Figure.6: 3D cube view of interpreted horizon showing fault pattern in Murud Depression (a) Geometry of surface corresponding to L-II and (b) Geometry of surface corresponding to H3B and (c) A horizon slice of Chicxulub Crater (after Sharpton et al.,1993)

(ii) Impact surface geometry:

Figure. 6a and 6b display the geometry of the surfaces corresponding to L-II and H3B. Surface geometry is almost similar for both. On both surfaces, concentric semi-circular to circular elevated ridges and lows are visible. Regional time and depth maps also reveal this distinctive circular area. All these ridges and lows are resulted from highly dipping circular, concentric faults (Figure.2 and 3). Large scale faults are radiating from Murud Depression and cross cutting the possible impact surface (L-II) (Figure.4). These undulatory surface morphology closely resembles that of Chicxulub crater of Yucatan peninsula, Mexico (Figure.6c) where similar geometry of impact surface is observed. On the impact surface, these radiating faults generated grooves were filled with ejecta material which gradually settled in these faulted lows resulting in additional thickness of low velocity material forming a distinct sag pull down below.

(iii) Hydrocarbon distribution:

(a)

Two geological sections were prepared (Figure.7a and Figure.7b) to understand the hydrocarbon distribution pattern and structural disposition in regional scale. Geological section in Figure.7a connecting DCS sector with Murud Depression was made through the wells Well-9, Well-8, Well-7 and Well-4. From hydrocarbon point of view it was observed that Well-4 drilled in Murud Depression area are devoid of hydrocarbon. Well-7 situated in the D-18 structure and further north of Murud Depression is having oil in Mukta Formation (H3A) level. Well-8 located NW of D-18 is producing oil from Panvel Formation and finally Well-9 is producing gas from Shallow L-II level. So hydrocarbons are encountered in time- transgressive sequences and away from Murud. Another geological section connecting HPB sector with Murud Depression (Figure.7b) was made through Well-4, Well-10, Well-11 and and Well-12. This section also show that Well-4 is devoid of hydrocarbon, Well-10 is having oil in Panna, Well-11 contains oil in Mukta level and Well-12 is having gas in Bombay level. So here also hydrocarbon occurrence is time- transgressive. The established hydrocarbon habitat of all the major fields in the vicinity of impact structure viz . Heera, MH etc. show dispersed pools from Basement fractures to shallow pools upto late Miocene. As for the HC distribution observed in MH, it is worth mentioning that the LIII carbonate reservoirs which host nearly half of all the established hydrocarbon reserves of Mumbai offshore, was favorably dispositioned at late Mid- Miocene, in terms of all critical elements of Petroleum system,The hydrocarbon distribution in D1(NBP) Field, which exhibits discrete charging in carbonate reservoir of Panvel and Ratnagiri Formations and non-occurrence of oil pools in older Mukta and Bassein reservoirs. In spite of the presence of source rock, reservoir (Primary reservoir was middle Eocene Bassein and early Eocene Devgarh carbonate), seal (Early Oligocene Mukta shales overlying Middle Eocene-Early Eocene Bassein- Devgarh carbonates acted as effective seals) and trapping mechanism (Independent structural closure at Miocene and early Eocen/ Palaeocene) in Murud Depression, hydrocarbon occurrences were found far away from Murud Depression. This might be possible due to a possible meteorite impact. Impact in Murud Depression, gave rise to regionally persistent radial faults and it seems that already generated hydrocarbons were migrated outwards and occupy suitable structures in the presently hydrocarbon producing areas of western offshore towards north. Another possible scenario is that the structures containing hydrocarbon in other sequences before the impact occurred got affected due to impact which resulted in Trap breach and dismigration of Primary pools to form secondary pools at shallower levels. BHT data for particular stratigraphic level especially for Basement and Panna/ Devgarh level has been integrated. After that iso-

Figure.7: Regional geological sections showing distribution of HC and structural disposition (a)connecting DCS sector and Murud Depression and (b)connecting HPB sector and Murud Depression

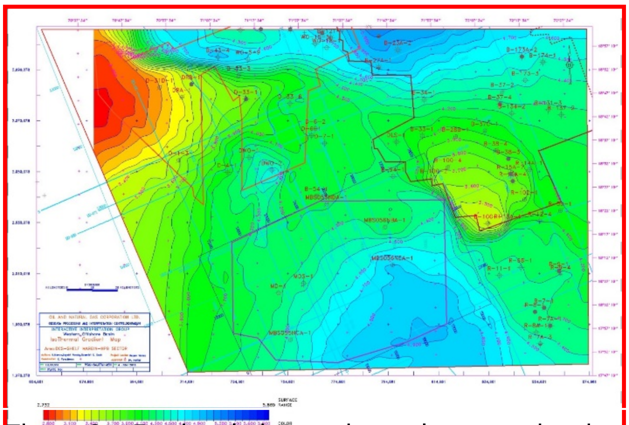


Figure.8: Regional isogeothermal map showing variation of geothermal gradient in and aroud Murud Depression. Gradients is maximum (4 deg c/100 m) im Murud and falls away from it

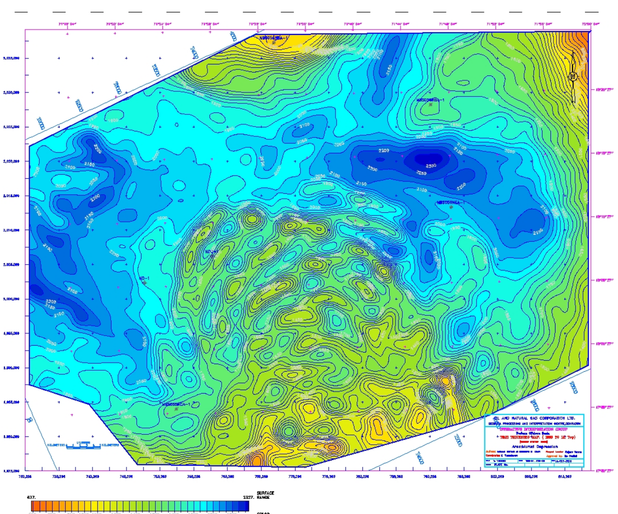


Figure.9: Isochronopach between L-II and H3B showing pack thickening in the periphery of central faulted zone

geothermal gradient map has been prepared (Figure.8). In Murud Depression area geothermal gradient reaches upto 4 deg-c/ 100 m, this is anomalously high. None of the deep wells (Well-4, Well-5 and Well-6) could be drilled upto target depth due to ultra-high temperature and complications. These ultra-high temperatures in Murud Depression also affect the petroleum system. Source rock with hydrocarbon generation potential becomes over matured and maturity wise source rock interval now falls in the gas zone.

8.2.5 Shale flowage below impact surface

Isochronopach map between H3B and L-II (Figure.9) shows significant pack thickening in the periphery of central faulted zone. At the same time the central part shows significant thickness reduction. Time slices of PSTM volume at different time intervals were captured (Figure.10). These time slices indicated that as we go deeper from 2700 ms where faults are conspicuous, most of the faults are getting diminished except a few fault. As we go down chaotic seismic reflection pattern gradually spread outward especially towards West to NW and towards SW. In the NW part, these chaotic reflection pattern moves around a relatively stable block. All these patterns indicate nothing but flowage of material out of central part of Murud Depression. Seismic section along IL 2400 (Figure.2) showed the effect of shale squeezing. It clearly depicts that thickness between L-II and H3B horizons increases significantly in the western side as well as in eastern side. In the eastern side strong reflectors due to presence of carbonate platform are observed. But, in the western part seismic reflection pattern look reflection free or devoid of layering. This indicates the presence of shaly / clayey material in the western side. This again indicates that Oligocene shale due to sudden shock/ pressure from above got squeezed from the central part. This shale could not flow towards east as there was a stable carbonate platform and thus it flowed towards SW and Western part of Murud Depression area.

8.2.6 Reactivation of older faults

Palaeostructural analysis using MOVE indicates that some of rift phase faults were active up to late Eocene time. They did not become active throughout the Oligocene and again got reactivated during Mid Miocene and extended up to Late Miocene. So the reactivation of these faults was triggered by a sudden Mid- Miocene event, large enough to activate such deep seated faults.

10. Conclusions:

The present study has brought out the following salient points which have a direct learning on hydrocarbon prospectivity as well as the observed hydrocarbon distribution and habitat of BHDCS and HPB sectors:

- The Murud Depression has witnessed a catastrophic meteoritic impact during the post Mid-Miocene time (after deposition of LII carbonates) which has severely influenced and altered the structural style observed in Murud Depression, BHDCS and HPB sectors.

- Seismic reflection patterns in section as well as surface geometry of correlated horizon have close resemblance with that of a complex crater

Figure.10:Time slices of PSTM volume at different time showing flowage of material. Black horizontal line on seismic sections correspond to particular time (a) time slice at 2700 ms showing radial fault pattern; (b) time slice at 3320 ms showing less faults intensity and movement of material (mark by yellow lines) outward and around a stable block (mark by red polygon) ; (c) time slice corresponding to 3560 ms showing further decrease of faults intensity and movement of material in same direction and (d) time slice corresponding to 4100 ms indicating the reapprearance of faults

- The radial fault pattern emanating from the centre of impact in Murud Depression appears to have affected the entire HPB sector from Heera platform in the immediate vicinity to Bassein High and Panna High in the northern part of HPB wherein the ENE-WSW trending faults have cut across the pre exiting NNW-SSE to N-S structural trends. These transverse trends are coeval to the impact event and bear evidence of strike- slip adjustments along their trend as response to the colossal stress accumulation at the impact site of Murud Depression. These ENE-WSW radial trends are also the locals for accumulation of low velocity clay fills along the grooves which result in velocity pull down sags in TWT sections. These clays are ejecta maerial coming out from impact centre in Murud Depression.

- The established hydrocarbon habitat of all the major fields in the vicinity of impact structure viz . Heera, MH etc. show dispersed pools from Basement fractures to shallow pools upto late Miocene. This coupled with the fact that peak expulsion from the source pools predate the impact event clearly point to the presence of preexisting pools which got breached and dismigration from these pools probably charged the shallower reservoirs. The hydrocarbon distribution in D1(NBP) Field, which exhibits discrete charging in carbonate reservoir of Panvel and Ratnagiri Formations and non-occurrence of oil pools in older Mukta and Bassein reservoirs, the low energy low GOR oil pools in Lower, Middle and Upper pays indicate a breached structure resulting in dismigration of HC from preexisting pools. As for the HC distribution observed in MH, it is worth mentioning that the LIII carbonate reservoirs which host nearly half of all the established hydrocarbon reserves of Mumbai offshore, was favorably dispositioned at late Mid- Miocene, in terms of all critical elements of Petroleum system, to receive both the dismigrated oil from fields like D18, D1 in south and also to host oil generated from the probable younger source pools which started expulsion post 18 Mabp.

- Iso-geothermal gradient map showed that geothermal gradient in Murud Depression area reaches upto 4 deg c/100m in H3B and H4 level. Such high gradient cannot be achieved through normal tectonic processes. Formation of central peak induced mantle upwelling and thus such ultra high temperatue

- Oligocene Shale flowage below impact L-II surface resulting from sudden shock of impact increased L-II pack thickness. This is evident from seismic reflection pattern observed on time slice and isochronopach between L-II and H3B
- Palinspatic structural restoration clearly indicated that some of the rift phase faults got reactivated due to a post mid Miocene meteoritic impact

- As for the possible effect of the nature and timing of impact on reservoir development it can be summarized that the intense shock waves generated during impact would have resulted in extensive fracturing and brecciation of older carbonates rocks resulting in carbonate breccia and fractured reservoirs. However, till date no carbonate breccia reservoirs have been established in any major fields. Fractured Basement reservoirs as encountered in MH and Heera fields also would have been partly impacted by this impact event. Therefore, focus should be given to explore for such fractured, brecciated reservoir in immediate vicinity of the impact crater i.e areas like B-54, B-94 etc.

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