Petrography, Fracture characterisation and migratory pathway analysis of Basement of Heera structure, Mumbai Offshore

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Basement exploration, fracture characterization, migratory pathway for the hydrocarbon**,** granite gneiss, EDS

Summary

In Mumbai Offshore Basin, the Heera structure is an important target for basement exploration. The present study, facilitated by availability of large number of cores, aims to map distribution and type of basement rocks, their fracture patterns and reservoir potential. The basement complex in the studied wells of Heera structure comprises dominantly of granite gneiss with minor mylonite and schists.

The prime reservoir characterised by granite gneiss depicts dual porosity with fracture developments both at macro and micro scales. The fracture density, in general increases in areas adjacent to major faults. Most of these fractures are filled with carbonaceous matter, ferruginous and carbonate cement. The latter cements which have deteriorated the reservoir quality are observed in wells very close to the Heera East fault (eg. Well A). However, in wells lying away from this major fault (Wells D, C and B) the fracture fillings are dominated by carbonaceous matter as indicated by high values of carbon element in EDS spectrum.

Heera structure forms an important area for Basement Exploration with good fracture density close to major faults. The microfractures in wells along these corridors especially those filled with carbonaceous matter have played an important role not only in enhancing the reservoir quality but also the migratory pathway for the hydrocarbon.

Introduction

Heera field is located in the central part of the Panna-Bassein Block and charged with hydrocarbons in Basement besides Panna, Bassein and Mukta formations. Basement of this structure is the second major hydrocarbon producing reservoir after the Mumbai High Basement reservoir in western offshore basin.
The focus of present study is on the petrography of the basement reservoirs and its fracture characterisation.

Theory and Method

Thirteen conventional cores from seven wells have been studied for basement characterisation (Fig.1). The following objectives were ascertained to study the conventional cores

- Lithological identification with degree of weathering/alteration, and their representation on standard electrical logs.
- To study the fracture pattern (micro and macro fractures as well as vug pores) system in terms of their nature, magnitude, intensity, orientation and fillings.
- Petrography of the representative core samples for their identification and nomenclature.
- Integration of data to understand the facies variations in space and depth to map distribution and type of basement rocks, producing zones and their reservoir quality.

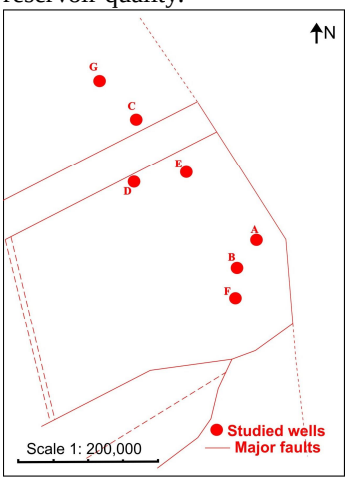

Fig1: Loaction map

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Observations

Well A:

In well A, Basement top is observed at 1351.24m. Oil indications have been observed after nitric acid and HF job. Fours cores CC-2, CC-3 and CC-4 have been cut in the basement. The basement rock in this well has unconformable/faulted contact with the overlying limestone and dominantly comprises mylonite (upper part of CC-2) and granite gneiss in the lower part.

Lithology: Mylonite is very finely crystalline rock, moderately altered.

Fracture analysis: There are two set of fractures. The large open fractures have dip values varying from 30 to 58^0. The microfractures are parallel to open fractures and some have high dip of 82^0. Microfractures are discontinuous with bifurcating nature and cut each other showing offset/displacement at places and mostly calcite filled (Fig 2). Many microfractures show crenulation. Fracture density is moderate to good. The youngest set of microfracture show 50 to 55^0 dip. Some fractures are clay/quartz filled.

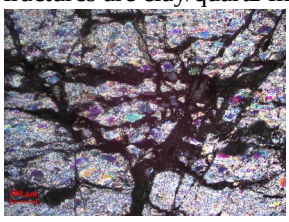

Fig2: Fracture intensity in Well A

Lithology: The granite gneiss in the lower part is predominantly composed of quartz, feldspars and hornblende as major constituent with minor biotite. The rock shows banding and gneissose texture.

Fracture analysis: In granite gneiss open fractures ranging in dip from 45 to 82^0 have been observed with moderate to good fracture density. Some microfractures are vertical and some are parallel to open fractures, dipping at 78^0. The microfractures are calcite filled and some are crenulated. Banding is common. SEM-EDS analysis reveals that fractures are filled with iron cement and clay minerals.(Fig 3.)

It seems that open fractures have gentle dips in the upper part (CC-2 mylonite zone) and moderate to steep dip downward in CC-3 and CC-4 (granite gneiss). In all the three cores microfractures are filled with calcite or iron cement.

Petrophysical studies were attempted on two whole core samples from CC-2, and one whole core and two plugs from CC-3. All the studied samples have shown very low porosity values in the range of 0.36-3.55 % (v/v). Both horizontal and vertical permeability values of the plugs and whole core are almost nil.

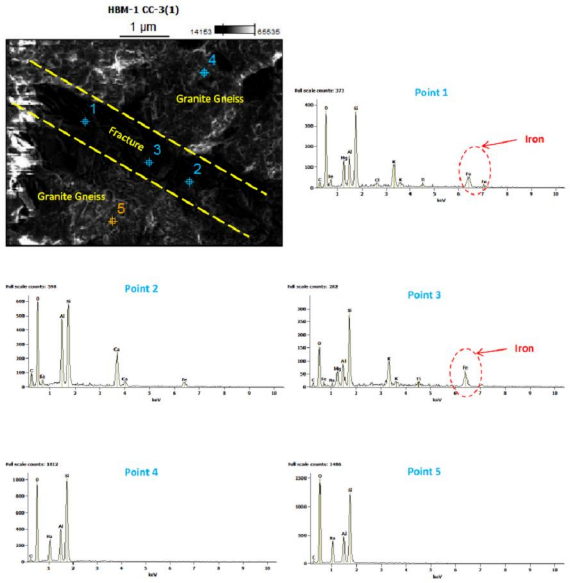

Fig3: EDS analysis for Fracture Characterization, Well A, CC-3

Well B:

In this well Basement top is observed at 1392m. No hydrocarbon shows were observed in the basement. The basement rock (CC-4, CC-5 and CC-6) in this well dominantly comprises granite gneiss with different degree of weathering/ alteration.

Lithology:

Granite gneiss is buff colored, hard and compact, massive showing alteration towards top. The altered gneissic rock at top (CC-4) consists of feldspar and ferromagnesium minerals that are altered to clayey or sericite material. Towards the middle of the core excellent horizontal orientation of ferromagnesium minerals is noticed. Pyrite in small quantities is also noticed along fracture or foliation planes. In the bottom portion of the core, concentration /clustering of ferromagnesium minerals like pyroxene, mica etc. is seen. The cores CC-6 and CC-5 are light grey, massive, hard and compact.

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Thin section petrography reveals that these rocks are gneisses which at places display augen structure. Minerlogically, gneiss is dominated by quartz, feldspar, pyroxene, amphibole; biotite, apatite and opaque minerals. Feldspar is intensively altered to sericite and clay minerals. Microfractures with fairly good density are filled with calcite and clayey matter. Besides, EDS analysis also indicate extensive fracture filling by carbon rich matter which may be remnants of hydrocarbon during migration.(Fig 4.)

Fracture analysis: Fractures of vertical to horizontal nature are observed which are at places filled with clayey or calcite material. There are open fractures with 45 to 50^0 dip. The micro fracture intensity gradually increases towards bottom. Mostly horizontal and vertical microfractures (up to 80^0 dip) are observed. The microfractures are crenulated at places and filled with calcite/clay.

Petrophysical studies of CC-4 & CC-6 have been carried out. All the studied samples have shown very low porosity values in the range of 0.72-3.24 % (v/v). Both horizontal and vertical permeability values of the plugs and whole core are almost nil.

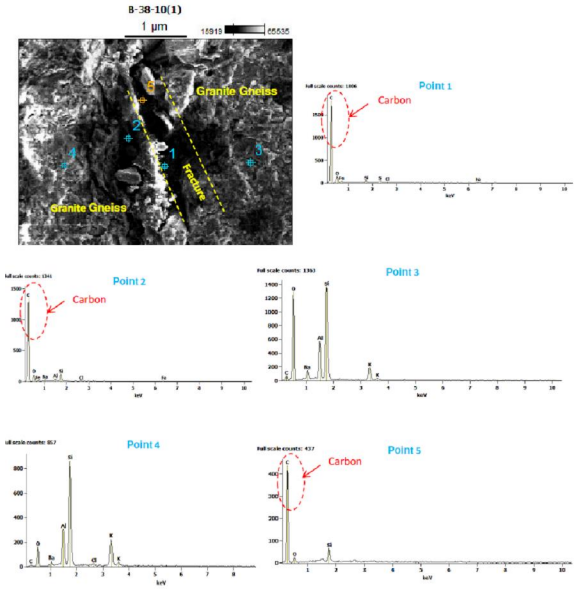

Fig4: EDS analysis for Fracture Characterization, Well B, CC-4

Well C:

In this well Basement top is observed at 1584m and drilled depth is 1640m. No hydrocarbon shows were observed in Basement. The Basement rock (CC-2) in this well comprises of hornblende gneiss with different degree of weathering/ alteration.

Lithology: Hornblend gneiss is greenish grey to grey, very hard and compact showing distinct compositional banding towards top and is massive gneiss at bottom. Disseminated secondary pyrite is observed along the fracture planes. Quartz veins cutting across the bands have been observed.

Microfacies: Petrographic study reveals that Hornblende gneiss is comprised of quartz, feldspar, hornblende, biotite, and accessory chlorite and iron oxide minerals. Microfractures are filled with secondary calcite and altered clay minerals.

Fracture analysis: Fractures varying in dip from vertical to horizontal have been observed with dominance of vertical fractures. A good intensity of open fractures is present with 60^0 to 65^0 dip. Microfractures are partially filled with calcite/clay minerals. At places in massive gneiss, the fractures show vuggy nature due to partial dissolution of fracture filled calcite minerals. EDS analysis also indicated extensive fracture filling by carbon elements which may be remnants of hydrocarbon during migration. (Fig 5.)

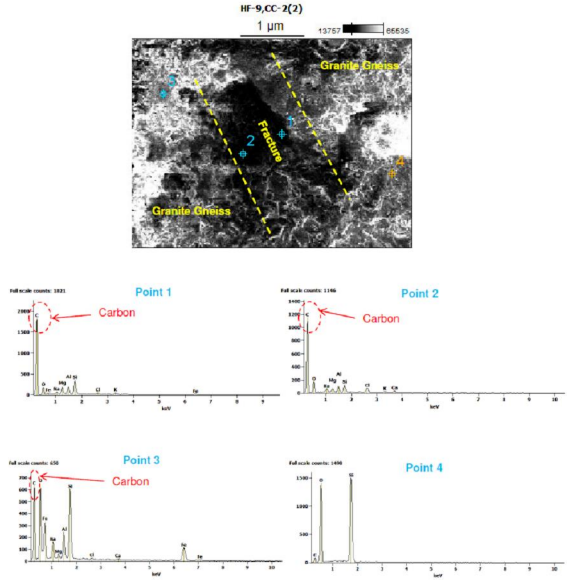

Fig5: EDS analysis for Fracture Characterization, Well C, CC-4

Well D:

In this well Basement top is observed at 1568m and three conventional cores (CC-10, CC-11 and CC-12)

have been cut in the Basement. The Basement rock in this well dominantly comprises granite gneiss and subordinate biotite schist.

Lithology: This core represents granite gneiss and thin layer of Schist. Granite Gneiss comprises of more felspars (dominated by plagioclase), ferromagnesian minerals and oxides (opaques) as compared to quartz. The crystals are generally euhedral to anhedral in shape and equidimensional in size. Microfacies studies of schist have revealed presence of quartz and biotite showing fibrous texture with pleochroic haloes, radiating at places with disseminated opaque minerals. EDS analysis also indicated extensive fracture filling with carbon elements which may be remnants of hydrocarbon during migration.

Fracture analysis: A moderately good intensity of open fractures is seen with 35 to 40^0 dip in CC-11 and highly fragmented zone with good to moderate intensity of open fractures is observed in CC-12. Occasionally vertical microfractures are also observed. Very few open microfractures are observed which are either parallel or at an angle of 35° to major open fracture. Intensity of microfractures is poor and mostly calcite filled forming a mesh/cut across.

Petrophysical study of one plug sample from CC-11, at 1578.9m has shown very low porosity values 2.43 % (v/v). Both horizontal and vertical permeability values of the plug are almost nil.

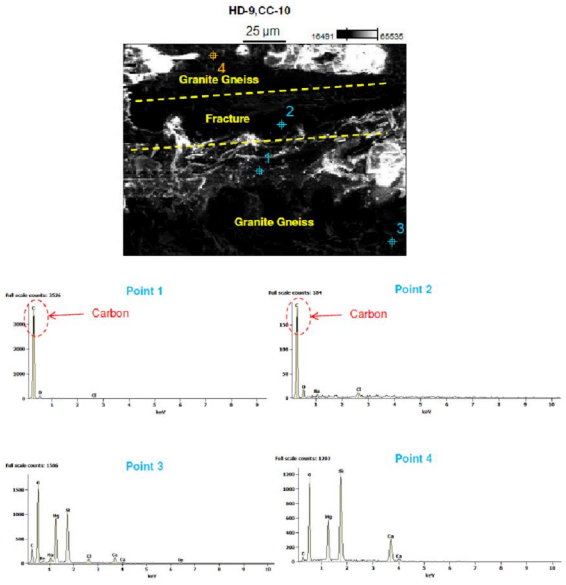

Fig6: EDS analysis for Fracture Characterization, Well D, CC-10

Well E:

In this well Basement top is observed at 1471m and was tested b/foot with observed flow of oil @ 781.4 bpd and gas @ 2873 m3/d. The basement rock (CC-3) in this well dominantly comprises Granite Gneiss.

Lithology: This core represents dark grey to bluish grey and light coloured granite gneiss with quartzo-feldspathic bands. Mineralogy of the gneiss is quartz, microcline feldspar, pyroxene and biotite.

Fracture analysis: Fragmented zone with abundant open and filled fractures of mm scale.

They are horizontal and inclined, dipping about 58 to 60^0. Numerous microfractures are observed which are either inclined or parallel to major open fractures, and filled with mica, secondary pyrite and other altered material. EDS analysis has indicated fracture filling by iron cement. Reservoir characteristics are fairly good.(Fig 7.)

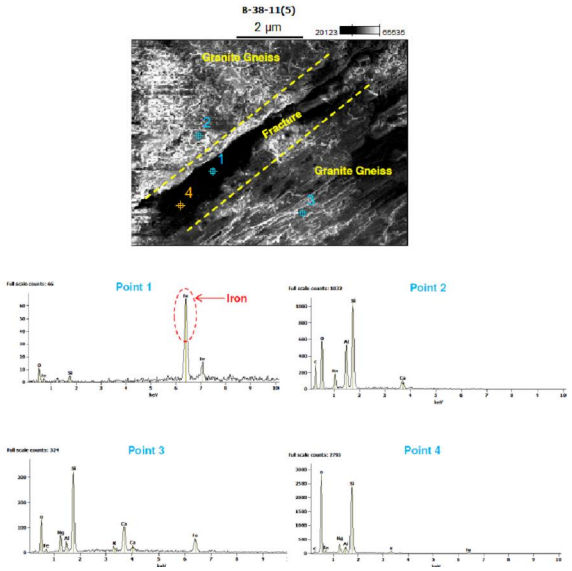

Fig7: EDS analysis for Fracture Characterization, Well E, CC-3

Well F

In this well Basement top is observed at 1587m. No hydrocarbon shows were observed in basement section. The basement rock (CC-5) in this well comprises of granite gneiss with different degree of weathering/ alteration.

Lithology: Grey to whitish grey with a reddish brown tint, hard, compact, showing bands of light and dark colour and calcareous. Micro-faulting is very intense and shows frequent offset and

displacement. The thin sections show coarse quartz showing microfractures cutting across the grains with abundant opaque material. The rock is rich in quartz and feldspar and represents granitic gneiss composition. The microfractures are filled with opaque.

Fracture analysis: Moderate intensity of open fractures are seen with 40 to 60^0 dip. A high degree of weathering is observed along fracture planes. Microfractures are parallel and inclined to major open fractures. Some microfractures are also horizontal. Banding/layering is observed which shows microfolding and microfaulting with an offset. The microfractures are mostly calcite filled and at places some carbonaceous matter is observed within microfractures. EDS analysis of fracture filling by opaques show carbon elements which may be remnants of hydrocarbon during migration (Fig 6.). Petrophysical studies of two core samples from CC-5 have been attempted. Both samples one whole core and one plug sample have shown porosity values in the range of 10.84 -19.11 % (v/v). Both horizontal and vertical permeability values of the plugs and whole core have shown permeability values in the range of 0.042 - 3.873 mD.

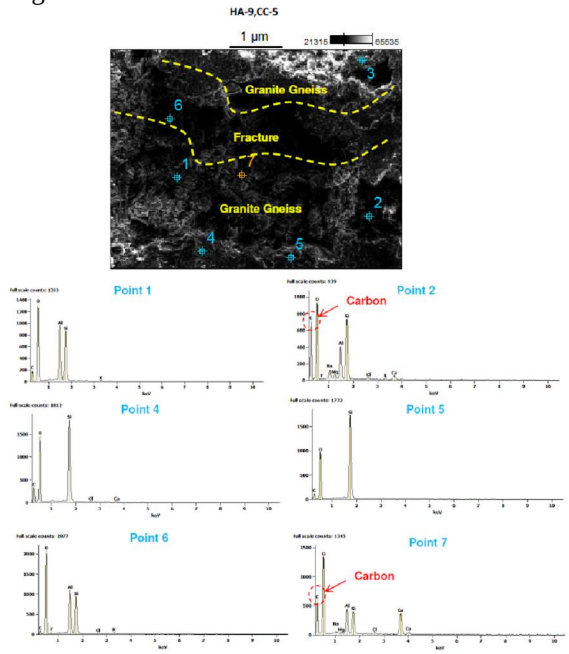

Fig8.: EDS analysis for Fracture Characterization, Well E, CC-3

Discussion

In Heera structure, Basement Complex comprises mainly of Granite Gneiss with minor mylonite, schist, and occasional dolerite intrusives. To understand the variation of basement rock in space and depth, three correlation profiles of have been prepared.

The NNW-SSE profile-I, passing through wells C, D, E, A, B and F indicates a high in NNW part around A and a gentle north-westerly slope and steep slope south of it. The facies is dominantly granite gneiss. However, variation in fracture characterisation has been observed. An increase in fracture density both at micro and macro scale has been observed in wells close to fault zone (wells A, B and D) with maximum fractures in well A.

The NW-SE profile in the central part, passing through wells F, B and A shows a gradual rise in slope towards south east. The facies is dominantly Granite Gneiss.

The NW-SE profile in the northern part passing through wells D, C and E also indicates a gentle rise in slope from well D to E. Granite gneiss is commonly observed in all the wells.

Petrophysical studies of selected plug samples shows an average range of porosity from 2 to 3%. The permeability is immeasurably low.

Based on detailed petrography and fracture pattern analysis, an attempt has been made to map the fracture patterns in the studied area. Most of the studied area is covered with granite gneiss. Some isolated occurrences of mylonite facies have been noticed in well A along the fault zone passing through these wells. The study reveals that the fracture density (both macro and micro type) increases in the areas close to major faults. Most of these fractures are filled with carbonaceous matter, ferruginous and carbonate cement. The presence of carbonaceous matter in the fractures in well D, C and B indicate that they are in the hydrocarbon migratory pathway. However, in the well A lying on a high, close to the fault, the microfractures are filled with ferruginous cement which has detoriated the reservoir quality. Incidentally, the wells D and E have

indicated presence of hydrocarbon, but well A has shown poor reservoir potential.

Conclusions

Å Basement Complex mainly comprises of granite gneiss with minor occurrences of schist, mylonite and dolerite intrusives. This is unlike Mumbai High structure where heterogeneous lithology varying from low grade metamorphic rocks like meta sedimentary, phyllite and schist to high grade metamorphics (Granite Gneiss) have been observed.

Å The porosity is mainly due fracture development both at micro and macro scale (dual porosity reservoir). An increase in fracture density has been observed in wells close to the fault zone.

Å SEM-EDS studies of micro fracture fillings have been attempted to understand the nature and type of fillings. Two distinct patterns have been observed. In some cases (well D, C and B), close to the major faults, the fracture fillings are dominated by carbonaceous matter, as indicated by high values of carbon element in EDS spectrum. In other cases (well A, E) presence of iron indicates ferruginous cement. In well F and C, both carbonaceous matter along with secondary carbonate cement (high value of Ca) have been observed.

Å Mapping of the nature of fracture filling reveals that most of the secondary fillings by ferruginous and carbonate cements is confined to areas very close to the Heera east fault (eg. well A). This has detoriated reservoir quality. However, in wells lying away from this fault, the effect of secondary filling is greatly reduced with consequent enhancement of their reservoir potential.

Å Heera structure forms an important area for Basement Exploration with good fracture density close to major faults. The microfractures in wells along these corridors especially those filled with carbonaceous matter have played an important role not only in enhancing the reservoir capacity but also the migratory pathway for the hydrocarbon.

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References

Bharkatya, D.K., Mohanty,R., Rajguru,A., Patade, T.C. and Kumar, A.S.K. (2014):Petrography and fracture characterisation of Basement Complex Rocks of Mumbai High, RGL , ONGC Mumbai report.

Kumar, A.S.K. (2012): Sedimentological and petrophysical studies on conventional cores of well X (Heera Structure), RGL , ONGC Mumbai report.

Bharkatya, D.K., Kumar, A.S.K., Mohanty.R., Patade.T (2014): Petrography, Fracture characterisation and Petrophysical studies of Basement of Heera structure, Mumbai Offshore.