Isotopic Characterization of Natural gases of Jaisalmer Basin, Rajasthan

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KEYWORDS:

Isotopes, paleosalinity, $\delta^{13}C$, hydrocarbons, Thermogenic origin, Biogenic origin

SUMMARY

This work is an attempt to characterize the natural gases present in the reservoirs in Jaisalmer Basin, Rajasthan on the basin of their molecular composition and stable carbon and hydrogen isotopic ratios for understanding the origin and accumulation of hydrocarbons in the basin. The result of 22 gases from 7 structures viz. Manhera Tibba, Kharatar, Bankia, Ghotaru, Chinnewala Tibba, Sadewala and Bakhri Tibba have been studied.

Gas to gas correlation on the basis of $\delta^{13}C$ methane and C_2+ concentration classifies these gases in to two genetic groups, namely, those accumulated in Tertiary sequences and those accumulated in Cretaceous sequences. Tertiary gases accumulated in Paleocene (Sanu Formation)/Early-Middle Eocene (Bandah & Khuiala Formations) is characterized by $\delta^{13}C$ methane value: -43.3 to -46.0 per mil and dry C_2+ is <1.0% with absence of hydrocarbons heavier than ethane. Gases accumulated by Cretaceous reservoirs are characterized by heavies $\delta^{13}C$ methane (-32.8 to -41.8 per mil) and full of spectrum of hydrocarbons upto pentane although the concentration of ethane is very low (<1.0%).

The Hydrogen isotopes on the other hand fail to distinguish between Tertiary and Cretaceous gases, (δD methane being similar -191 to -207 per mil). This similarity implies similar paleosalinity of the environmental waters during photo-synthesis of organic matter. Similarly, nitrogen and carbon isotope ratios in associated nitrogen ($\delta^{15}N$, -0.02 to 2.4 per mil) and carbon di oxide ($\delta^{13}C$, -11.2 to -17.3 per mil) do not discriminate between Tertiary and Cretaceous gases. These similarities suggest that the type of organic matter and mechanism of formation of N_2 and CO_2 are similar for Tertiary and Cretaceous gases. On a $\delta^{13}C$ methane –δD methane genetic diagram, all the gases have been classified as thermogenic origin. Spatial variation of N_2 concentration (44-82%) may be because of long distance migration, even the low value of $\delta^{15}N$ rules out the high grade metamorphic origin of N_2.

Since the basin has largely derived humic type of organic matter, generation of large quantities of nitrogen from the decomposition of organic matter in the deeper part of the basin cannot be ruled out. Presence of helium which is believed to be of igneous origin, however supports the view that some nitrogen may be of igneous origin also. Carbon isotopic compositions of associated CO2 in studied wells are also similar ($\delta^{13}C$: -11.2 to -17.3 per mil with the average of -15.0 per mil) and support generation of CO2 from decomposition of organic matter. Thus, it seems that generation of methane, nitrogen and CO2 has taken place by the process of thermal decomposition of humic organic matter, possibly at high maturities in the deeper part of the basin and after migration gases may have been trapped in present locales.

The gases of Jaisalmer basin are characterized by high nitrogen content up to 82% and detectable quantity of helium (0.02 to 0.08%). Due to immaturity of sediments, Tertiary gases have been interpreted to be a mixture of locally formed bacterial gases and migratory thermal gases of deeper origin. The Cretaceous gases may also have originated at a deeper source of high maturity and then migrated to the present locales. Deeper sequences, therefore, hold promise of hydrocarbon prospects. However, absence of metamorphic methane and low N_2/He ratio suggest that a sedimentary/igneous source of nitrogen is more probable.

INTRODUCTION:

The Jaisalmer Basin is a part of large Indus Basin, subdivided in four tectonic units, namely, Jaisalmer Mari High, Shahgarh, Kisangarh and Miajlar sub-basins (Misra et al. 1993) (Fig.1). Most of the exploration activities by ONGC has been centered over Jaisalmer Mari High trending NW-SE. Gas discovery has been established from 7 structures, namely, Manhera Tibba, Kharatar, Bankia, Ghotaru, Chinnewala Tibba, Sadewala and Bakhri Tibba. The structures are gas bearing in Tertiary reservoirs or Cretaceous reservoirs or both.

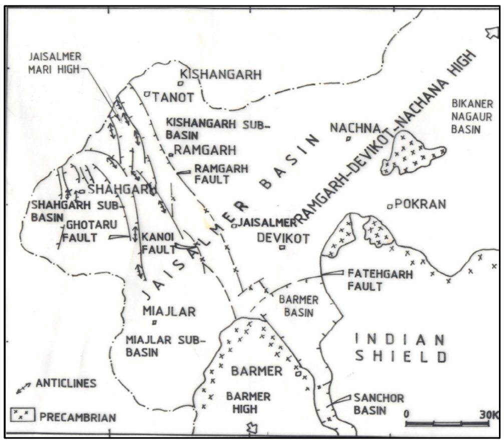

Fig.1 Different tectonic units of Jaisalmer Basin

Comprehensive geochemical work has been carried out on source rocks (Mittal et al., 1997) and gases (Banerjie et al., 1992, Ghidiyal et al., 1995). So for such an extensive study on isotopic characterization of methane, nitrogen and CO_2 of the natural gas in Jaisalmer basin seems unavailable. The work was carried out with objective to better understand the genesis of hydrocarbon in the basin. Data of 22 gas samples from different structures and different reservoirs were analyzed to understand the compositional heterogeneity and genetic characteristic of the gases. $^{13}C_{CH4}$ and $^{13}C_{Co2}$ can be used to distinguise between Tertiary and Cretaceous Gases (Fig.2).

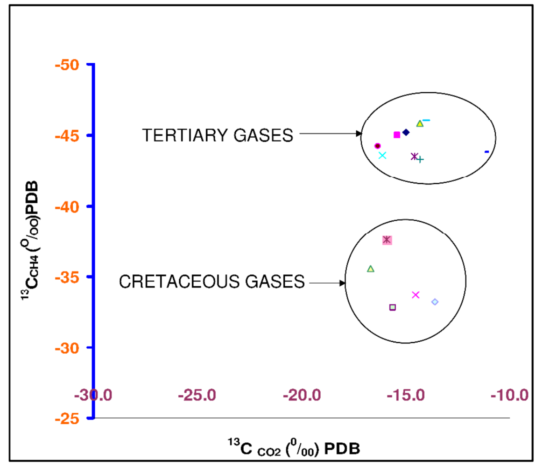

Fig: 2. Isotopic correlation of Tertiary and Cretaceous gases

CARBON AND HYDROGEN ISOTOPE RATIO OF NATURAL GASES:

Natural gas has been found in a wide variety of environments. While methane is always a major constituent of the gas, other components may be higher hydrocarbons (ethane, propane, butane), CO_2, H_2S, N_2 and rare gases. Two different types of gas occurrence can be distinguished-biogenic and thermogenic gases. The most powerful parameter in distinguishing both type being their Carbon and hydrogen isotope composition along with the relative abundances of methane to other hydrocarbon gases (Schoell, 1980, 1983; Whiticar et al., 1986; Whiticar, 1994, Stolper et al., 2015). $\delta^{13}C_{CH4}$ values between -110 to -50 per mil have often been considered indicative of biogenic gases, as the kinetic fractionation on the organic material by methanogenic bacteria in methane very much depleted in $\delta^{13}C_{CH4}$ while those -50 to -20 $‰_0$ indicative of thermogenic gases (Schoell, 1980; Whiticar, 1994). Similarly, marine bacterial methane has δD value between -250 and -170%0 while biogenic methane in fresh water sediment is strongly depleted in δD and the value varies between -400 to 250$‰_0$(Whicar et al., 1986). The combination of carbon and hydrogen isotope analysis of natural gases is a powerful tool to discriminate the different origin of gases. The plot of $\delta^{13}C$ versus δD (fig. 3 after Faber et al., 1992) can be used to distinguish the biogenic and thermogenic gases from different environment.

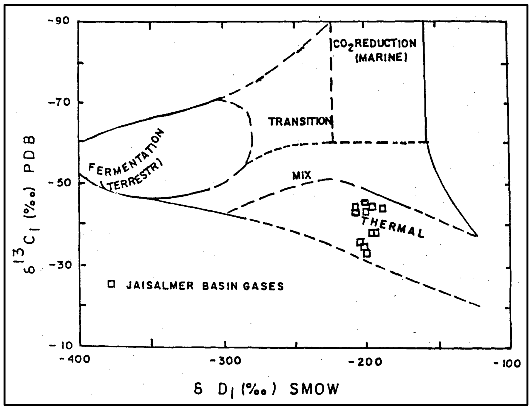

Fig.3 $\delta^{13}C$ versus δD plot to distinguished between biogenic and thermogenic gases.

$\delta^{13}C_{CH4}$ ISOTOPIC CHARACTERIZATION OF GASES:

$\delta^{13}C_{CH4}$ Isotopic Characterization of Gases is related to three main stages of thermal evolution of organic matter in sedimentary rocks i.e. Diagenetic (-90 to -55 ‰), Catagenetic (-55 to -40 ‰) and Metagenetic (-40 to -25 ‰). This is the classification based on primary processes. Secondary effects like isotope equilibrium fractionation, bacterial degradation and mixing may occasionally become significant (V. Banerjee et al., 1992).

A. TERTIARY GASES AND THEIR ORIGIN:

Chemical composition data indicate that the gases contain mainly methane and very small quantities of ethane (<0.1%) and higher hydrocarbons are practically absent. The carbon isotopic composition, $\delta^{13}C$ of methane in the Tertiary gases range from -43.3 to -46.0 ‰ PDB, suggesting similarity in the origin of these gases. The carbon isotopic ratio (-43.5 to -46.0 ‰ PDB) and hydrogen isotopic ratio (-192 to - 207 ‰, SMOW) of Tertiary gases suggest that they are wet thermogenic gases. Schoell (1983) developed a plot of δD verses $\delta^{13}C$ of Methane to recognize different genetic types of gases, besides distinguishing bacterial and thermal gases, this plot gives a rough indication of maturity, with the most mature gases falling in the lower right corner of dry thermogenic gas (Td)(Fig 4). The Tertiary gases fall in the region bound by To, i.e. thermogenic gas with oil, this suggests that the Tertiary gases are mature gases associated with oil, but the composition of gases show that it is dry with almost negligible concentration of higher hydrocarbons. This phenomenon is not uncommon in migratory gases; the gases can migrate away from oil and still have To signatures on Schoell plot (Schoell, 1983). The source rock studies have indicated that the Tertiary sediments are immature and are incapable of generating thermogenic gases with isotopically heavier carbon. The possible explanation of the presence of thermogenic gases in Tertiary reservoirs is that the gases are generated and migrated from deeper source and the stripping of higher hydrocarbons has taken place during upward migration. The presence of detectable quantities of Helium (0.02 to 0.05%) and high concentration of Nitrogen (43.99 to 74.35%) with isotopic composition of $\delta^{15}N$ -0.02 to 2.4%; also indicates the upward migration of gases from deeper source at higher maturities and contribution of Helium and Nitrogen from igneous basement rocks (V. Banarjee et al., 1992). The Schoell plot indicating the position of Tertiary gases on them are shown in Figs. 4 and 5.

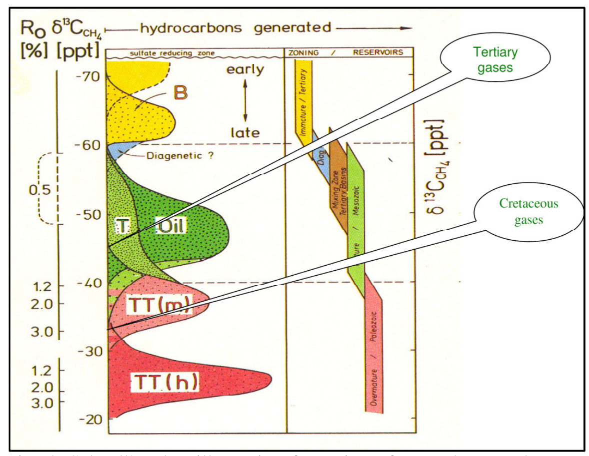

Fig. 4. Schoell's Plot, illustrating formation of natural gas and petroleum in relation to maturity of organic matter.

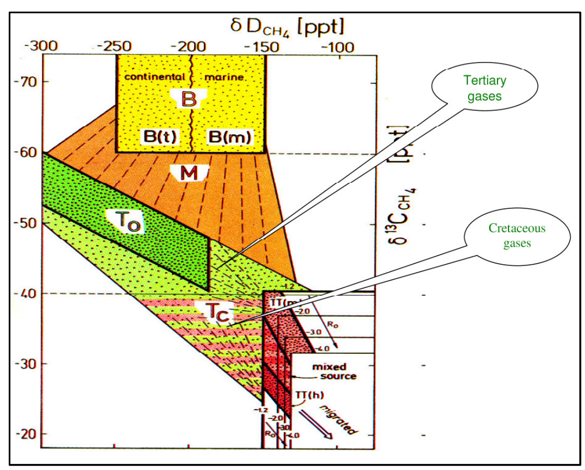

Fig.5. Schoell's Plot of methane dD vs d13C for characterizing the origin of natural gases. B = Bacterial gases, M = Mixed gases, To = thermogenic gas with oil, Tc = thermogenic gas with condensate

B. CRETACEOUS GASES AND THEIR ORIGIN:

The Cretaceous gases are wet and contain hydrocarbons up to pentanes. The C2+ content vary from 0.35 to 1.96%. The gases are isotopically heavier; the $\delta^{13}C$ values of methane vary from -32.8 to -37.8 per mil. The isotopic values and maturity relationship indicates that these gases have migrated to the present locales (V. Banarjee et al.,1992).

HYDROGEN, CARBON DI OXIDE AND NITROGEN ISOTOPIC COMPOSITION OF TERTIARY AND CRETACEOUS GASES:

Tertiary and Cretaceous gases don't distinguish themselves on the basis of hydrogen isotope ratios of methane (δD, % SMOW) and the values are in the range, - 191.0 to -207.0, this implies similar paleo-salinities of environmental waters during photosynthesis of organic matter. Similarly the Carbon isotopic composition of associated CO_2 (-11.2 to -17.3) and Nitrogen isotopic composition (-0.02 to 2.4) of associated nitrogen also don't distinguish themselves on the basis of age of reservoirs. This similarity suggests that the type of organic matter and mechanism of formation of nitrogen and carbon dioxide are similar for Tertiary and Cretaceous gases. It is inferred on the basis of isotopic data that generation of methane, nitrogen and carbon dioxide has taken place by the same process, that is, by thermal decomposition of humic organic matter at higher maturities and after long distance migration gases might have been trapped in the present locales.

originated from the source organic matter having maturity above 1.2 %VRo. This is further substantiated by the Schoell plot indicating genetic relationship with source (Fig. 4), where these gases fall in the region of Tc, thermogenic gas with condensate. This suggests that like Tertiary gases, Cretaceous reservoired gases also have originated at a deeper source of higher maturity and then

CONCLUSIONS:

1. Tertiary gases from Manhera Tibba, Bakhri Tibba and Ghotaru have a similar origin, they are mainly migratory gases from deeper origin, being mixed with locally formed biogenic gases at shallow depth.
2. Carbon isotope ratio of Cretaceous gases suggest an overmature source and thus indicated migration of gases from deeper part of the basin. Some variation in the C-isotope values of methane may be due to mixing of locally generated diagenetic/early thermal gases with the deep seated migratory gases in different proportions.
3. Use of both carbon and hydrogen isotope ratios of methane leads to the thermogenic origin of gases. Hydrogen isotope ration could not be used as an indicator of maturity which is better reflected in carbon isotopes.
4. Hydrogen isotope ratios of gases irrespective of their occurrence (Cretaceous/Tertiary) are similar, implying similar paleosalinity of environmental waters during photosynthesis of organic matter. The gases could be differentiated only on the basis of their carbon isotope ration.
5. Carbon isotopic composition of associated CO_2 and Nitrogen isotopic composition of associated nitrogen suggest that the type of organic matter and mechanism of formation of N_2 and CO_2 is similar to all gases irrespective of age of reservoirs.

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