Surface gas seepages in the on-land Mahanadi Basin: Implications for shallow biogenic gas prospectivity

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ABSTRACT

Exploration of biogenic methane has attracted worldwide attention in the light of its ubiquitous occurrence in soils at shallow depths and also due to the low cost of drilling for its exploitation. The on-land part of Mahanadi basin, covered by the Quaternary Mahanadi delta, has evidenced surface gas seepages at several locations which turned out to be biogenic in origin as indicated by the compositional and carbon isotope analysis. A unique attempt has been made to utilize the geological, hydrogeochemical and electrolog informations of the tube-wells drilled for groundwater by Central Ground Water Board to study the occurrence, depth and aerial distribution of the potential reservoir zones charged with biogenic gas, which led to some important observations and leads.

The empirical study of electrologs suggested that normal resistivity values great than 60 ohm.m might indicate presence of biogenic gas in the reservoir zones. Using this criterion, 6 tube-wells have been identified as having positive indication from amongst the 13 considered.The study also further identified that the high resistivity zones are confined to shallow depths between 30m and 200m below the ground level. The scattered nature of the gas seepage sites and tube-wells with positive indications suggests possible presence of localized pools of few square kilometres area in accordance with the reservoir facies of the fluvial depositional environment. The hydrogeochemical study of the groundwater indicated that they are characterized by low sulfate, high bicarbonate and low calcium ion concentrations, which are favourable for biogenic gas generation.

INTRODUCTION

Organic matter decomposed by the action of anaerobic micro-organisms (methanogens) at low temperatures produce biogenic gas. (Reeburgh and Heggie, 1977; Rice and Claypool, 1981; Rosenfeld and Silvermann, 1959). This process is ubiquitous in natural environments where the gas produced gets trapped in shallow and immature sediments (Rice and Claypool, 1981) such as swamps, shallow marine bays, and freshwater lakes with anoxic conditions and so on. (Vilks et al., 1974; Rashid and Vilks, 1977; Schoell, 1983; Whiticar et al., 1986; Albert et al., 1998; Okayar and Ediger,1999). These gases produced by methanogenic micro-organisms are rich in methane and are not associated with any kind of oil pools related to conventional hydrocarbons (Rice and Claypool, 1981; Schoell, 1983; Flood gate and Judd, 1992). Therefore, the biogenic gas is characterized by higher concentrations of methane (generally more than 98%) and lower concentrations of higher molecular weight hydrocarbons (generally less than 1–2%) with some CO_2 and N_2. The $\delta^{13}C$ CH_4 values for these gases generally range from −55‰ to −90‰ and can be as low as −110‰ (Schoell, 1988; Whiticar et al., 1986).

The shallower strata of many sedimentary basins are found charged with the biogenic gases in both unconventional and conventional reservoirs (Rice and Claypool, 1981; Martini et al., 1998; Shurr and Ridgley, 2002; Brown, 2011). It is estimated that about 20% of the discovered gas reserves in the world are of biogenic in origin (Rice and Claypool, 1981). It is further expected that more such biogenic gas reserves will be discovered in the future (Rice and Claypool, 1981; Kvenvolden, 1988, 1995; Kotelnikova, 2002; Shurr and Ridgley, 2002). In recent years, commercial biogenic gas discoveries have been made in many sedimentary basins in China(Lin et al., 2004; Yuqi Dang et al., 2008; Chun-Ming Lin et al., 2010; YanhuaShuai et al., 2013; Shuichang Zhang et al., 2013; Yunyan Ni et al., 2013).

Biogenic gas has many advantages over conventional hydrocarbon resources. It is wide spread in occurrence and found at shallow depths. Further, it has very cost effective in terms of exploration and development (Lin et al., 2004).

The on-land part of Mahanadi Basin, located in the east coast of India, has also evidenced several such biogenic gas seepages that have been reported in the print media and also in television. Few of such incidents have been brought to the notice of Oil and Natural Gas Corporation (ONGC). Compositional and carbon isotope studies were conducted on the gas samples and further study was carried out by incorporating the geoscientific information from the Basic Data Reports (BDRs) collected from the Central Ground Water Board (CGWB), Bhubaneswar Office. This paper presents the observations and findings made from the study and discusses the possibility of biogenic gas prospectivity in the study area (Fig.1) and recommends the same methodology and approach for other such prospective areas in India.

GEOLOGICAL SETTING

The Mahanadi basin forms one of the five sedimentary basins in the east coast of India (Fig.1). The on-land part of Mahanadi basin and its adjacent offshore part have been extensively studied by many workers in terms of geological evolution, geophysical characteristics, stratigraphy and hydrocarbon prospectivity (e.g. Anand et al.,2002; Babu Rao et al.,1982; Bharali et al., 1991; Das, 1996; Kaila et al., 1987; Kalachand Sain et al., 2002; Fuloria et al., 1992, 1993; Mahalik, 2000; Subrahmanyam et al., 2008; Vinod and Asis, 2003).

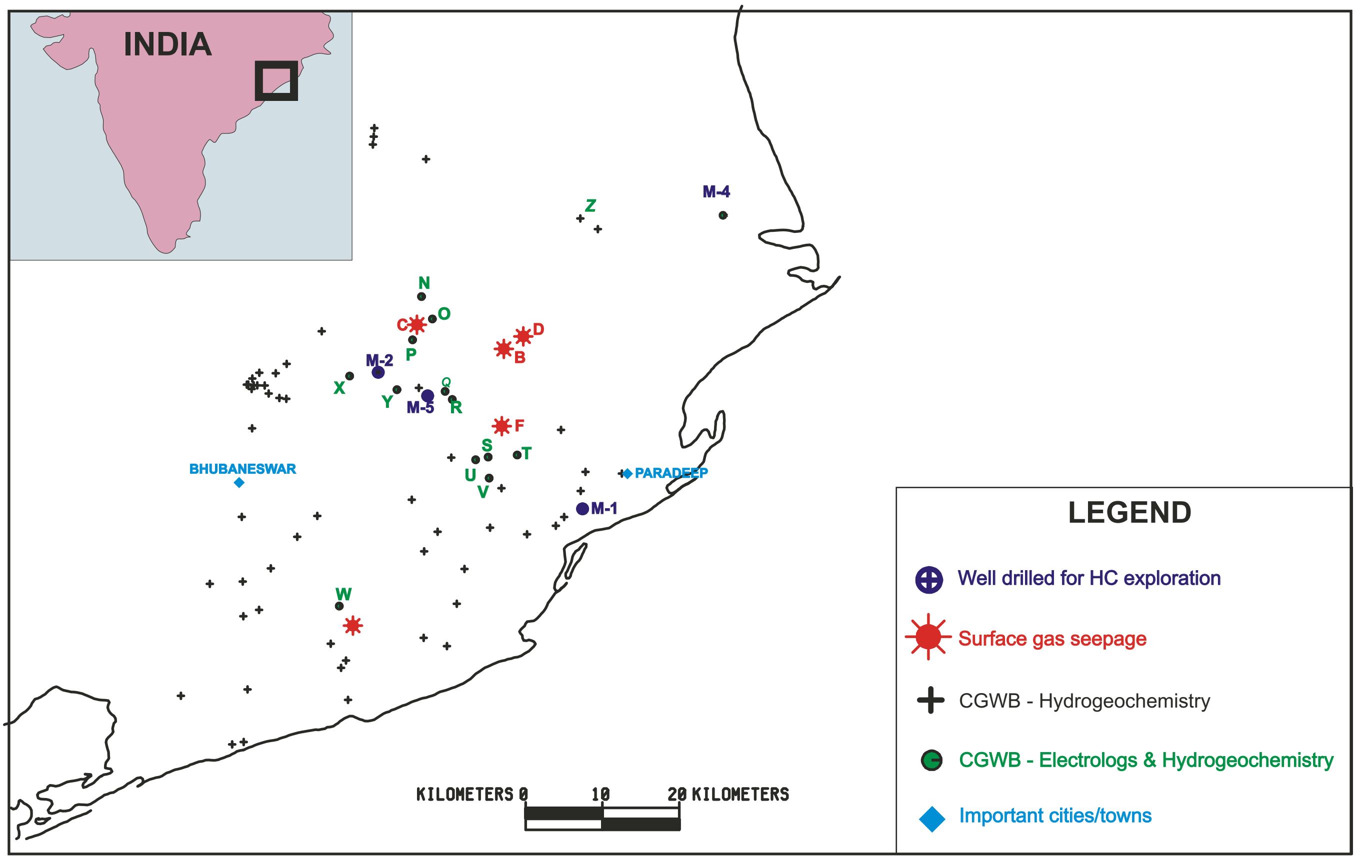

Fig. 1: Location map of the study area of on-land Mahanadi Basin

The Mahanadi basin in general and its on-land part in particular, has four distinct geological stages in its development: (i) The formation of the craton crystallines and Eastern ghat high-grade terrain belonging to the Pre-Cambrian age (Archean and Proterozoic) that forms the basement, (ii) The formation of the coal bearing Gondwana in grabens within the basement crystallines during Upper Carboniferous to early Cretaceous period, (iii) The formation of east coast basin due to rifting of Indian plate from Australia and Antarctica during end of Mesozoic and (iv) Deposition of marine and deltaic sediments beginning from the Upper Cretaceous till the present. Hence, the sediments of Upper Jurassic/Early Cretaceous to Recent are resting on the Pre-Cambrian basement in the on-land Mahanadi basin. The modern Mahanadi delta of Quaternary age conceals the underlying sediments in the Mahanadi on-land basin.

Five exploratory wells, represented as M1 to M5 in Figure 1 (Fuloria et al., 1992; Directorate General of Hydrocarbons, India website), have been drilled so far in the onland Mahanadi basin with some indications of hydrocarbons. As the geological information from the shallow sections of these wells is not available they were not considered in the present study.

BIOGENIC GAS GENESIS

The favourable condition for biogenic methane production are anoxic environment, moderate temperatures (<75^0C) and a moderate stage of compaction that provides sufficient space for bacterial activity. Hence, most biogenic gas is generated at a shallow depth. The recent and shallow sediments are enriched with bacteria which get their energy by enzymatic decomposition of the organic matter. This microbial activity produces gases like CO_2, H_2, H_2S, CH_4 and N_2. Methane survives as the major components of free gases in shallow sediments.

The primary methogenesis is dominated by two pathways: the bacterial carbonate reduction and bacterial methyl-type fermentation. The metabolic reduction of CO_2 to CH_4 with hydrogen as electron source is considered to be the dominant pathway for biogenic methane formation in the saline environments, such as marshes and marine sediments (e.g., Belyaev et al., 1975; Oremland and Taylor, 1978; Whiticar, 1999). During the process of carbondioxide reduction, hydrogen is incorporated directly from the formation water with a constant fractionation (Whiticar et al., 1986):

$$CO_2 + 8H^+ + 8e \rightarrow CH_4 + 2H_2O$$

The acetate fermentation can be represented by the general reaction (Whiticar, 1999; Whiticar et al., 1986):

$$CH_3COO^- + H_2O \rightarrow CH_4 + HCO_3^- \text{ (bicarbonate)}$$

Thus acetate fermentation leads to increase in concentration of bicarbonate in formation water present in biogenic gas reservoir. The acetate fermentation is regarded to be responsible for roughly 70% of the methanogenesis in freshwater environments (e.g., Fey et al., 2004; Koyama, 1964; Takai, 1970). Hence, due to different methanogenic pathways, the methane formed by CO_2 reduction in marine sediments is often more depleted in ^{13}C and more enriched in deuterium than that formed by the transfer of a methyl group (Whiticar et al., 1986).

IONIC CHARACTERISTICS OF THE GROUNDWATER ASSOCIATED WITH BIOGENIC GAS

Sulfate

In anaerobic condition, bacteria use oxidized forms of organic matter, particularly carbohydrates. Although hydrogen is produced under different conditions, it is almost immediately utilized for reduction of nitrogen, sulphur and oxygen compounds. Most ground waters encounter and dissolve sulfate minerals along the paths of flow. As the groundwater enter deeper, oxygen-poor (anoxic) parts of flow systems, biochemical reduction of the dissolved sulfate precipitates sulfides and thereby depleting the sulfate content of the waters. Biogenic methane is produced by methanogenic bacteria in an anoxic environment with low sulfate concentrations, high organic matter and under optimum conditions of temperature. If sulfate is abundant (more than 10meqv/l which is 480ppm), methane is not formed till sulfate is reduced or its concentration becomes low (Rice and Claypool, 1981). Sulfate is completely absent or present in low concentration in fresh water environments while it is more in the marine environment. Some research suggests that the generation of methane occurs concurrently with the sulfate-reduction process, depending on the methanogenic species present (Oremland et al., 1982).

Bicarbonate

Waters produced with biogenic methane are rich in dissolved bicarbonate, which is a direct product of both the sulfate-reduction and methane-fermentation processes (Freeze and Cherry, 1979). It is not a by-product in the biochemical process of CO_2 reduction. The universal presence of elevated bicarbonate with biogenic methane, regardless of methane origin, suggests that biochemical reduction of sulfate is the primary bicarbonate producer in the formation waters.

Calcium and magnesium

The formation waters associated with biogenic gas reservoir are almost devoid of the divalent cations such as calcium and magnesium, but contain high concentrations of sodium. The predominant process for calcium and magnesium depletion is attributed to the precipitation of calcite and dolomite due to reduced solubility in the presence of the elevated concentrations of bicarbonate (Van Voast, W.A., 2003). Bicarbonate enrichment inherent with the sulfate-reduction process causes precipitation of calcite and dolomite, producing the high-bicarbonate, low-sulfate, low-calcium, and low-magnesium character of the formation waters.

DATA AND METHODOLOGY

Surface gas seepages and gas sample analysis

Several gas seepages have been reported from the on-land Mahanadi Basin, mostly at locations where tube-wells were dug for ground water. Details of five such seepage locations– (i) “A”, (ii) “B”, (iii) “C”, (iv) “D”, and (v) “E” have been collected (Fig.1). Among the five locations, information regarding two locations has been gathered from secondary sources. The first seepage, as far as known, was reported at a place named “A”, near Puri. This news was reported in NDTV during November 2007 where a family was shown to use the gas for cooking purpose also. Oil India Limited (OIL) had collected the gas sample from this location and the compositional and calorific value analysis was done. Copy of this report has been obtained from OIL. Further survey of newspapers had shown that a similar incident was reported from “B” village near Kendrapada as published in the daily Times of India on 13thDecember 2007. According to the report there was pungent smell in the water drawn from a tube well at “B” village and caught fire on lighting. No chemical analysis data for this location is available.

Subsequently, gas seepages have been reported to ONGC from three locations to which a team of geoscientists visited to study the phenomenon and to collect the gas and water samples for compositional and isotopic analysis. These three locations are: (i) village “C”of Cuttack District (ii) village “D” of District Kendrapara and (iii) village “E”, Puri District. “C” and “D” are located in the north of the study area while “E” is located to the south (Fig.1). The gas samples collected from these three seepage locations have been analysed by using gas chromatographic methods to know their primary composition and further carbon isotope studies have been carried out.

CGWB Basic Data Reports

The Central Ground Water Board drills exploratory and peizometric wells in the process of ground water exploration in India. The geoscientific information of the wells is presented in the Basic Data Reports (BDRs). A total of 102 BDRs pertaining to the study area have been collected from CGWB, Bhubaneswar. Dates of these BDRs range from 1970's to present decade. Pertinent information like location of the wells, lithology encountered etc. is available in all the BDRs.

Some BDRs also contain Self-Potential (SP) and Normal Resistivity (Res) electrologs. Though electrologs are available for 16 wells, keeping in mind the legibility of the logs in the scanned BDRs a total of 13 wells are considered for the present study to identify reservoir zones of sand/ sandstones having anomalous resistivity that corroborate with gas seepage zones (Fig.1). As the sediments are shallow and comparatively younger, and have common provenance and compaction, the influence of lithological factors over the resistivity of reservoir zones is assumed to be minimal. The Normal Resistivity curves presented in these BDRs were recorded in different spacings like 0.1m, 0.4m, and 1.6m or 0.25ft and 2.5ft or 16in and 64in spacings. Among these, 0.4m (15.748in), 16in and 2.5ft normal resistivity curves have been considered. Though most of the logs are presented in Ohm.m scale, they are in ohm. ft scale in some others. Hence, necessary scale correction has been done for the study.

Most of the BDRs also have the chemical analysis data of the groundwater comprising the concentration of important anions and cations. Mostly, reservoir zones defined by sand/sandstone containing freshwater were subjected to draw-down analysis and the water collected was chemically analysed. Multiple zones were tested in some wells while in some others single zone was tested. Thus, the water collected at the surface might be derived from multiple reservoir zones in some wells. However, the analysis of the groundwater with reference to sulfate, bicarbonate, and calcium ions may give insights for possible indications of shallow biogenic gas accumulations in the form of significance of the ion concentration, and the origin and pathways of biogenic methane. BDRs of a total of 65 wells have this data and are considered for the present study (Fig.1). Contour maps are prepared for the ion concentrations of sulfate, bicarbonate and calcium ions, and sulfate/ bicarbonate ratio to identify areas conducive for biogenic gas generation.

RESULTS

Gas compositional analysis

The result of the gas chromatographic analysis of the gas samples (Table 1) has shown that the gases contain only methane as their predominant hydrocarbon component. For the seepage location at “A”, the gas consists of 85.76% of Methane, 3.38% of CO_2 and 10.86% of Nitrogen. The calorific value of this gas has been determined to be about 7000 Kcal/M3, which is quite high given the biogenic origin of the gas (ONGC lab report, 2007).

Table 1: Gas chromatographic analysis report of the gas samples

Sl.No.	Location	Composition % (v/v)		
		Methane	Nitrogen	CO2
1	"A"	85.76	10.86	3.38
2	"C"	82.44	16.2	1.36
3	"D"	2.21	83.67	14.12
4	"E"	62.61	4.77	32.62

The compositional analysis of the gas sample at “C” has indicated that the gas consists of 82.44% of methane, 16.20% of CO_2 and 1.36% of nitrogen. The gas sample at “D” has indicated that the gas consists of 2.21% of methane, 14.12% of CO_2 and 83.67% of nitrogen indicating contamination by air. Lastly, the gas samples collected from “E” 62.61% of methane, 32.62% of CO_2 and 4.77% of nitrogen.

Carbon isotope analysis of gas samples

The carbon isotope analysis of the gas samples collected by ONGC team from the three locations “C”, “D” and “E”, has been summarized in Table-2. It is observed that the $\delta^{13}C1$ values of the gas samples range from - 61.9‰ to - 67.1‰, for all the samples confirming biogenic nature of the origin of the gas.

Table 2: Stable carbon isotope composition of seepage gases from locations "E", "C" and "D"

Sl.No.	Location	Stable Carbon Isotope Values ($\delta^{13}C$ ‰)	
		δ^{13}C1	δ^{13}CO2
1	"E" (1)	-61.9	-2.6
2	"E" (2)	-62.1	-3.3
3	"C" (1)	-66.2	-24.1
4	"C" (2)	-67.1	-23.8
5	"D" (1)	-66.6	-25.3
6	"D" (2)	-66.3	-25.6

The cross-plot of $\delta^{13}C$ of CH_4 Vs. $\delta^{13}C$ of CO_2 is shown in Figure 2. The cross-plot shows distinct characteristics for the location "E" when compared with the locations "C" and "D".The carbon isotopes of "E" gas are heavier in both CO_2 and CH_4 when compared with the values of "C" and "D", more so for the carbon isotopes of CO_2.

Normal Resistivity log studies

Among the three gas seepage sites in the north of the study area, gas seepage was observed from a depth of 39.6m in a tube-well at "C". Interestingly, in a nearby CGWB tube-well at "O", located at an aerial distance of about 3 to 4 km, the coarser clastics zone defined by sand and gravels from the depth of 36.12 to 49.52 shows high resistivity of about 94 ohm.m (Fig. 3). The high resistivity nature could be due to gas or freshwater mixed with gas. Since gas seepage has been reported at "C" approximately at the same depth, the "O" tube-well log signature could be fairly attributed to biogenic gas. This offered an important lead to study the eletrologsfrom the BDRs and to corroborate them with gas findings in the nearby areas.

The study of normal resistivity logs of the CGWB wells indicated that the resistivity values for saline water mostly range from 0 ohm.m to 15-20 ohm.m and for freshwater they range between 10-20ohm.m and 50-60 ohm.m. Hence, the maximum resistivity of 60 ohm.m can be considered as the threshold and the reservoir zones that are characterized by resistivity values greater than 60 ohm.m can be considered as probable biogenic gas bearing zones. Figure 4 displays the resistivity value distribution in the 13 wells considered for the present study. In addition to the well "O" discussed above, the wells at "W", "R", "V", "X", and "Y" show resistivity

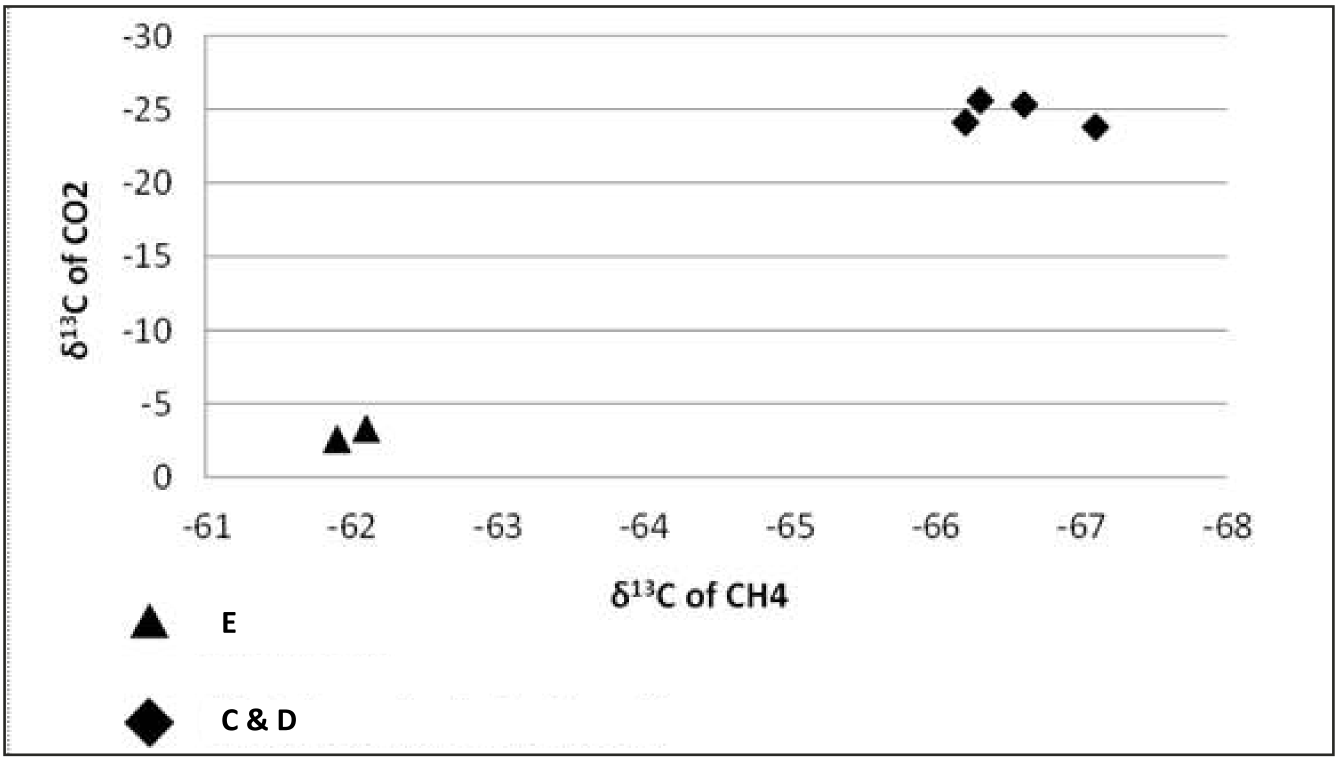

Fig. 2: Cross plot between $\delta^{13}C$ of CH_4 and $\delta^{13}C$ of CO_2 of gas samples from locations "E", "C" and "D"

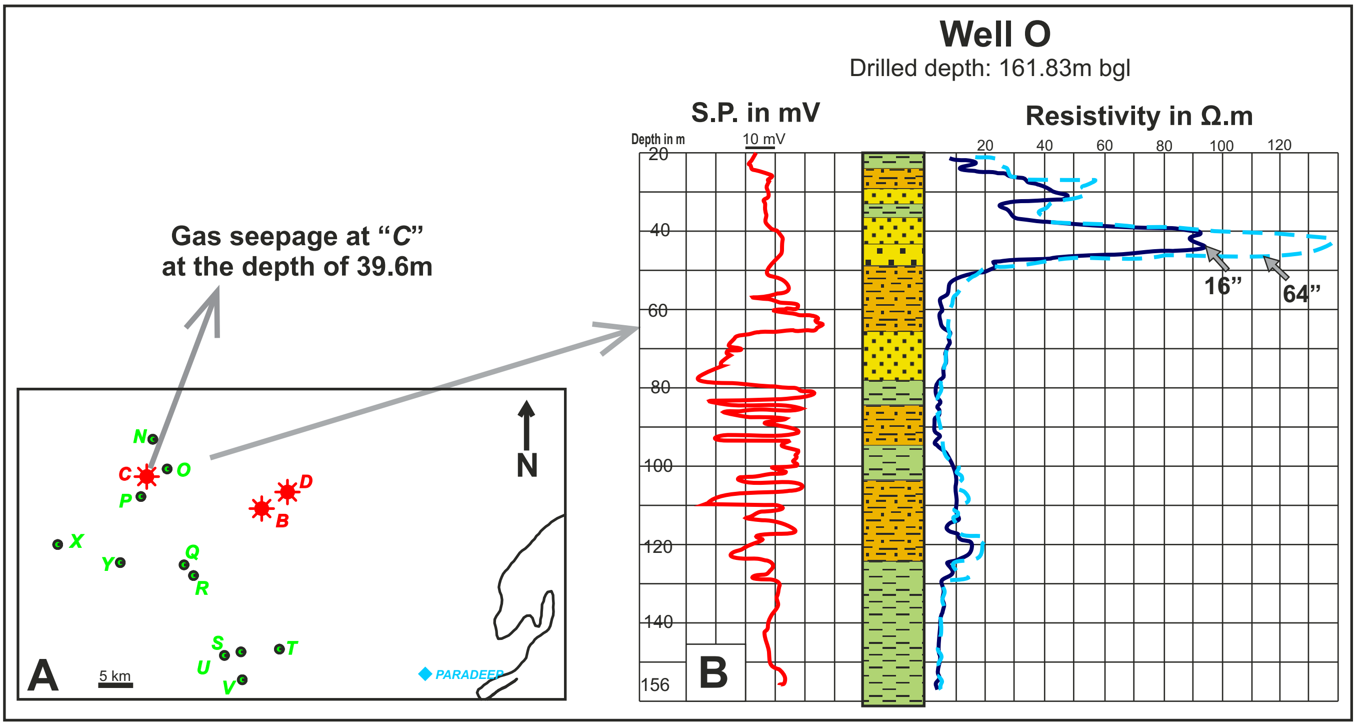

Fig. 3: Correlation between gas seepage depth at “C” and high resistivity reservoir zone of in CGWB tube-well at “O”. A) Map showing location of “C” and “O” B) electrolog of the CGWB tube-well at “O”.

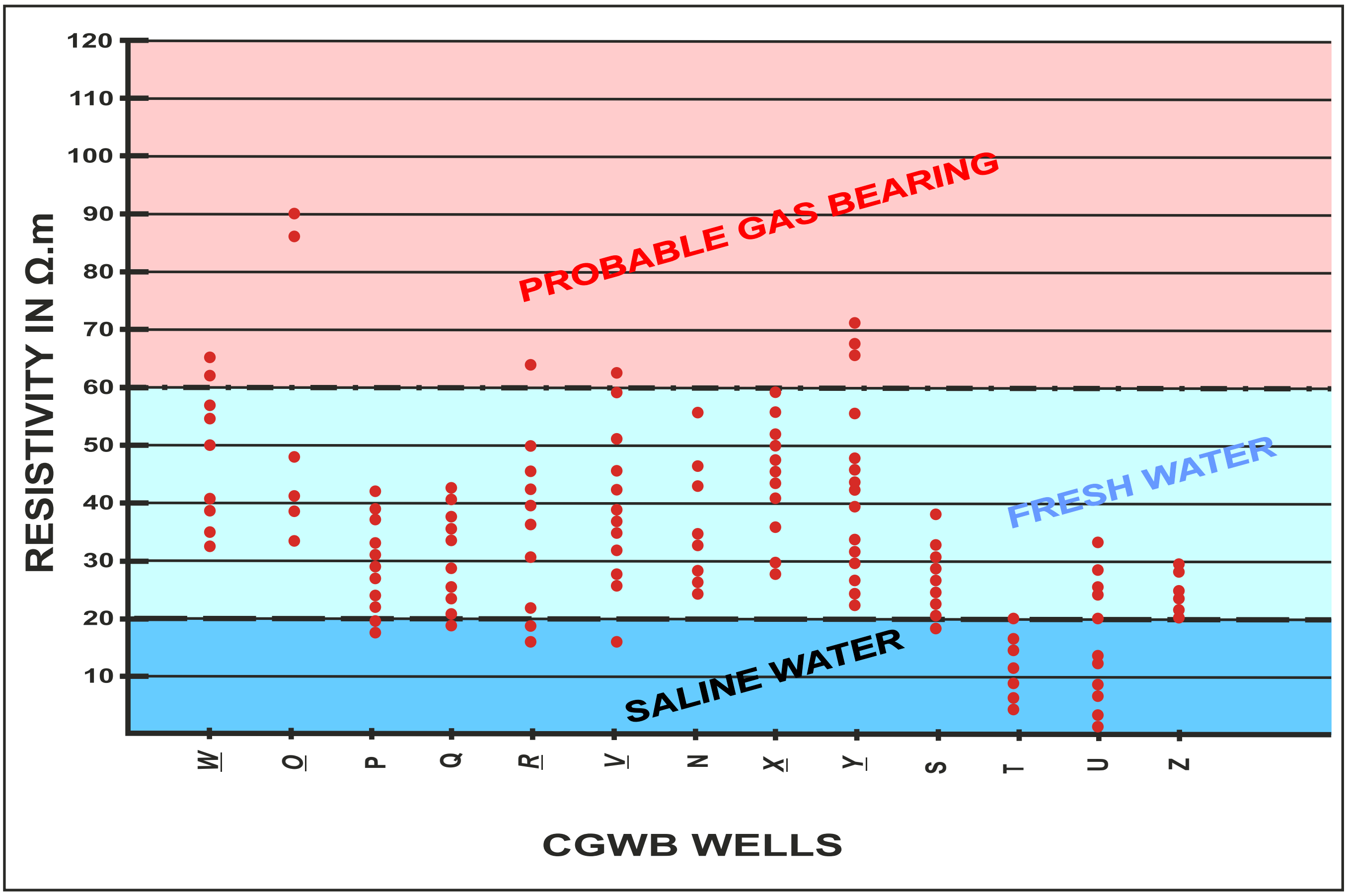

Fig. 4: Graph showing the range of resistivity values of the 13 CGWB wells considered for the study.

values higher than 60 ohm.m. Among these, the well at “W” displays resistivity values greater than 60 ohm.m in some sand zones which corroborates with the gas seepages observed at nearby locations of “A” and “E” (Fig.1). Thus among the 13 wells studied, 6 wells have zones having resistivity values great than 60 ohm.m. Figure 5 shows the electrologs and lithocolumns of these 6 wells. These zones may be interesting in terms of biogenic gas charge.

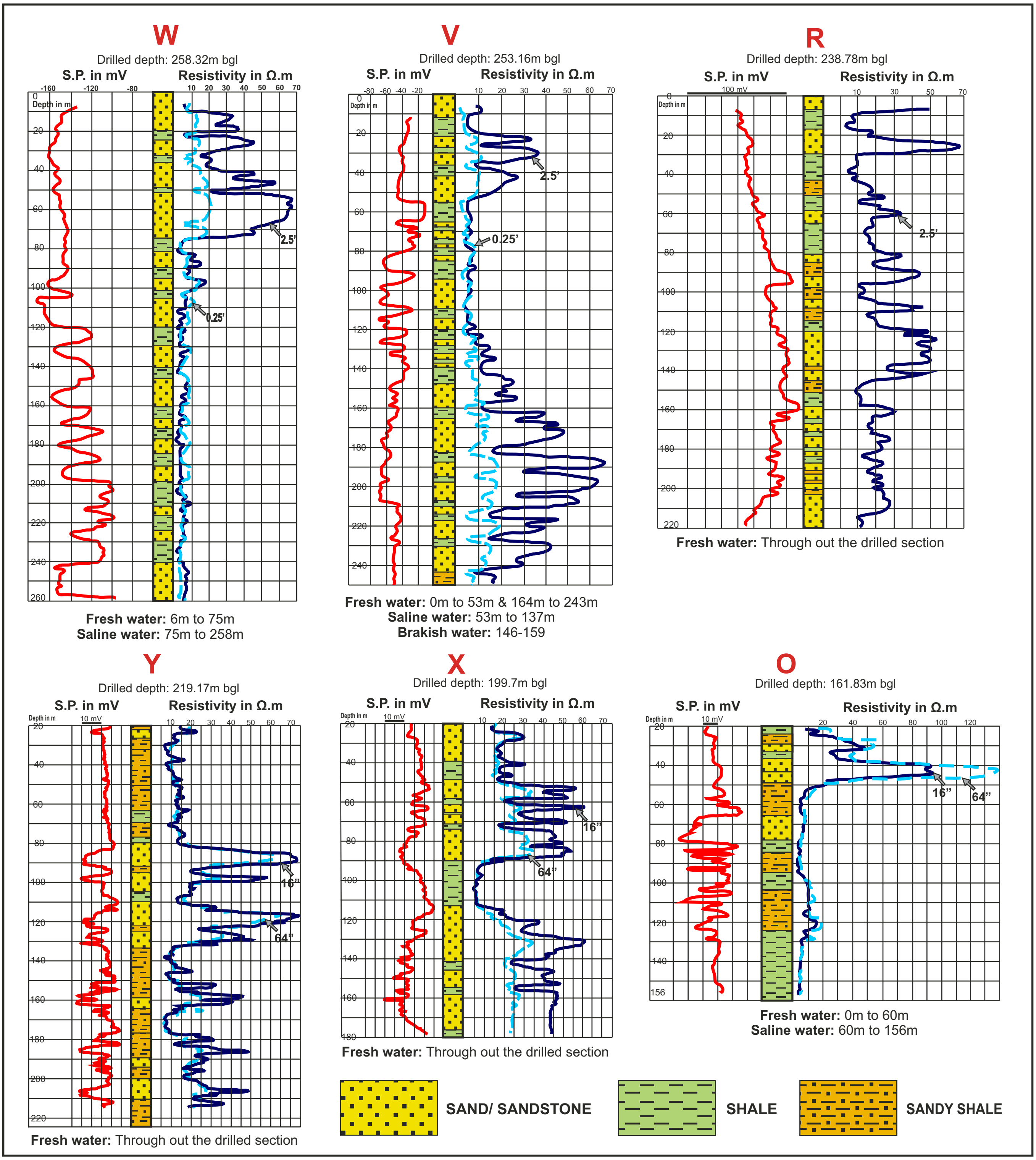

Fig. 5: Lithocolumn and electrologs of the six wells that have recorded normal resistivity values great than 60 ohm.m

The cross-plot between depth and resistivity is presented in the Figure 6. This shows that the sand zones having resistivity values more than 60 ohm.m are mostly confined between 30m and 200m depth. Prominent clustering can be observed at the depths of 50m, 80m, 110 to140m and 180 to 200m.

Groundwater Geochemical study of CGWB wells

Suphate Concentration

From the sulfate contour map (Fig. 7) of the onland Mahanadi Basin, particularly in the southern portion of the study area around Puri, it can be observed that sulfate concentration is low to nil in the coastal areas (around seepage locations it is about 11.5ppm). Similarly, in the north of the study area, although it is showing an increasing trend towards the northern part (> 80ppm), it is still far below the threshold limit (10meEqv/l = 480ppm) to prevent methanogenesis (Van Voast, 2003). Thus the sulfate concentration of the entire study area is either nil or present in very low concentration favouring the bacterial methanogenisis.

Bicarbonate Concentration

Figure 8 shows the bicarbonate concentration contour map of the study area. It can be noted that bicarbonate concentration is high (> 200 ppm) around seepage locations, where the sulfate concentration is also low. The concentration increases towards the coastal area to the south (>500ppm). Similarly, in the central part of the study area it shows high values (400-500ppm). It is also showing an increasing trend towards the interior and northern parts. This can be attributed to acetate fermentation which is the preferred pathway of methanogenesis in relatively fresh water sediments (Whiticar et al., 1986).

Sulfate/Bicarbonate Ratio

Waters produced with biogenic methane are low in sulfate/bicarbonate ratio. From the suphate/ bicarbonate ratio contour map (Fig. 9), it can be observed that sulfate/bicarbonate concentration is low (<0.03) around seepage locations. The ratio

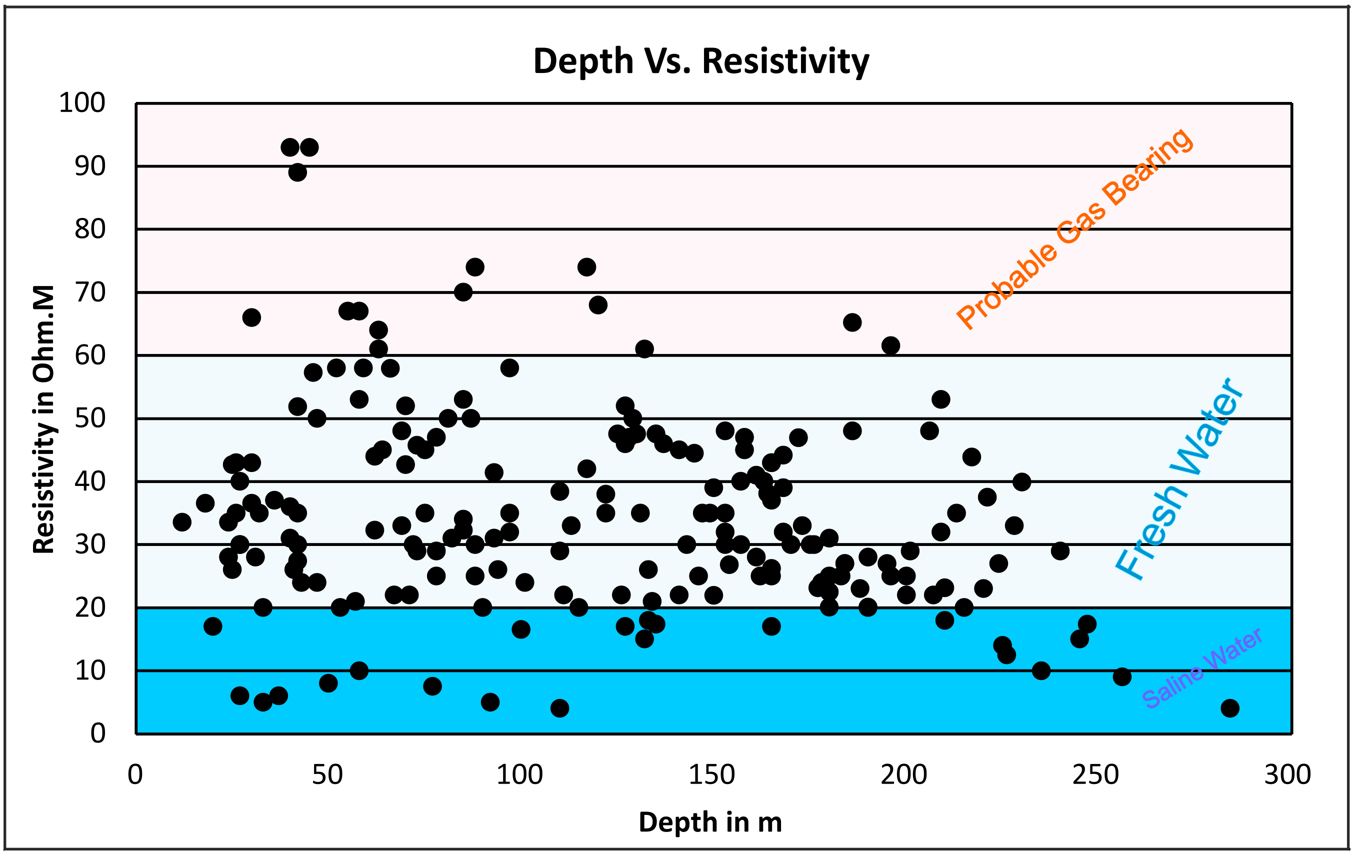

Fig. 6: The cross plot between depth and resisitivity of the reservoir zones in the 13 wells

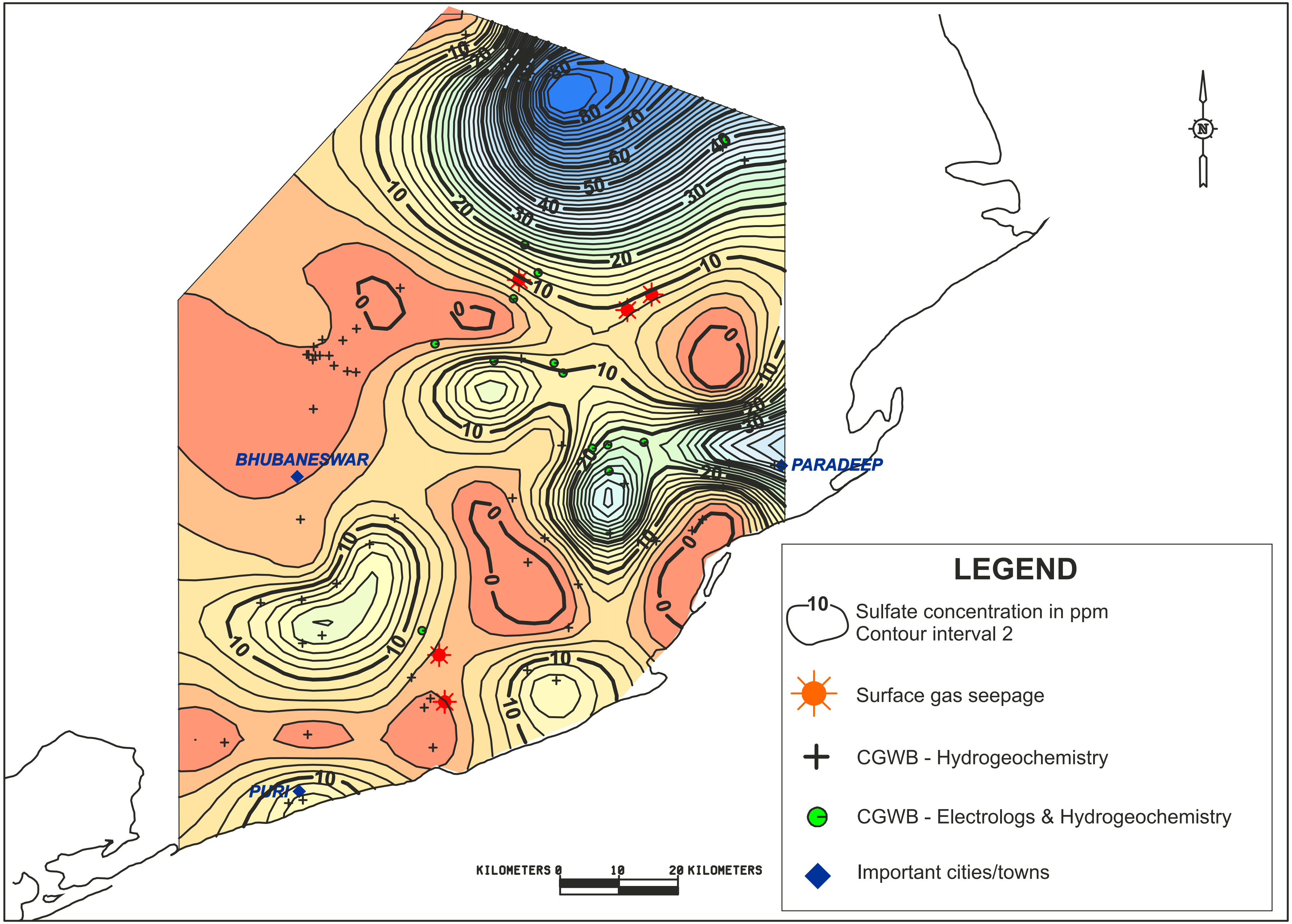

Fig. 7: Sulfate concentration in the study area

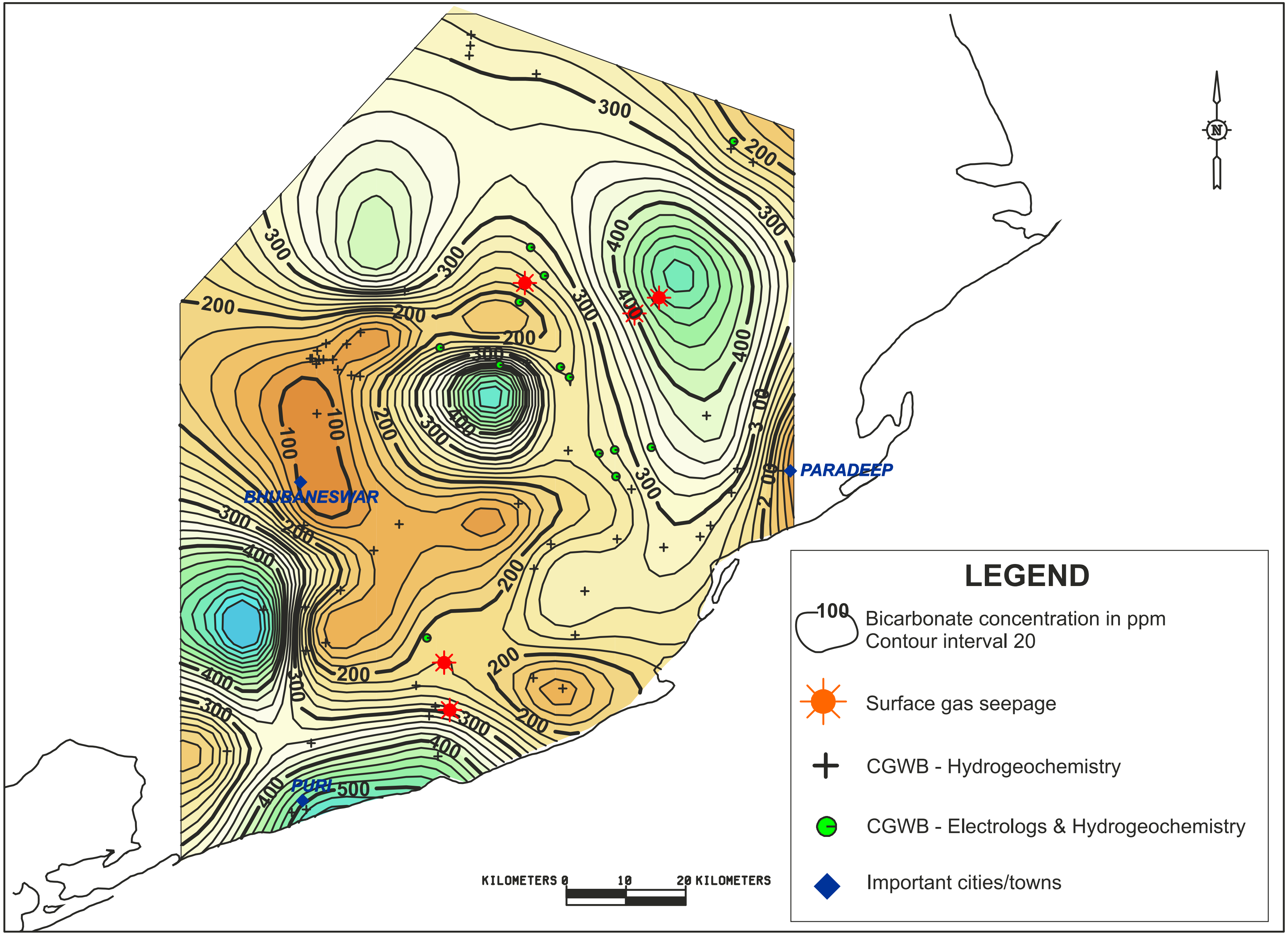

Fig. 8: Bicarbonate concentration in the study area

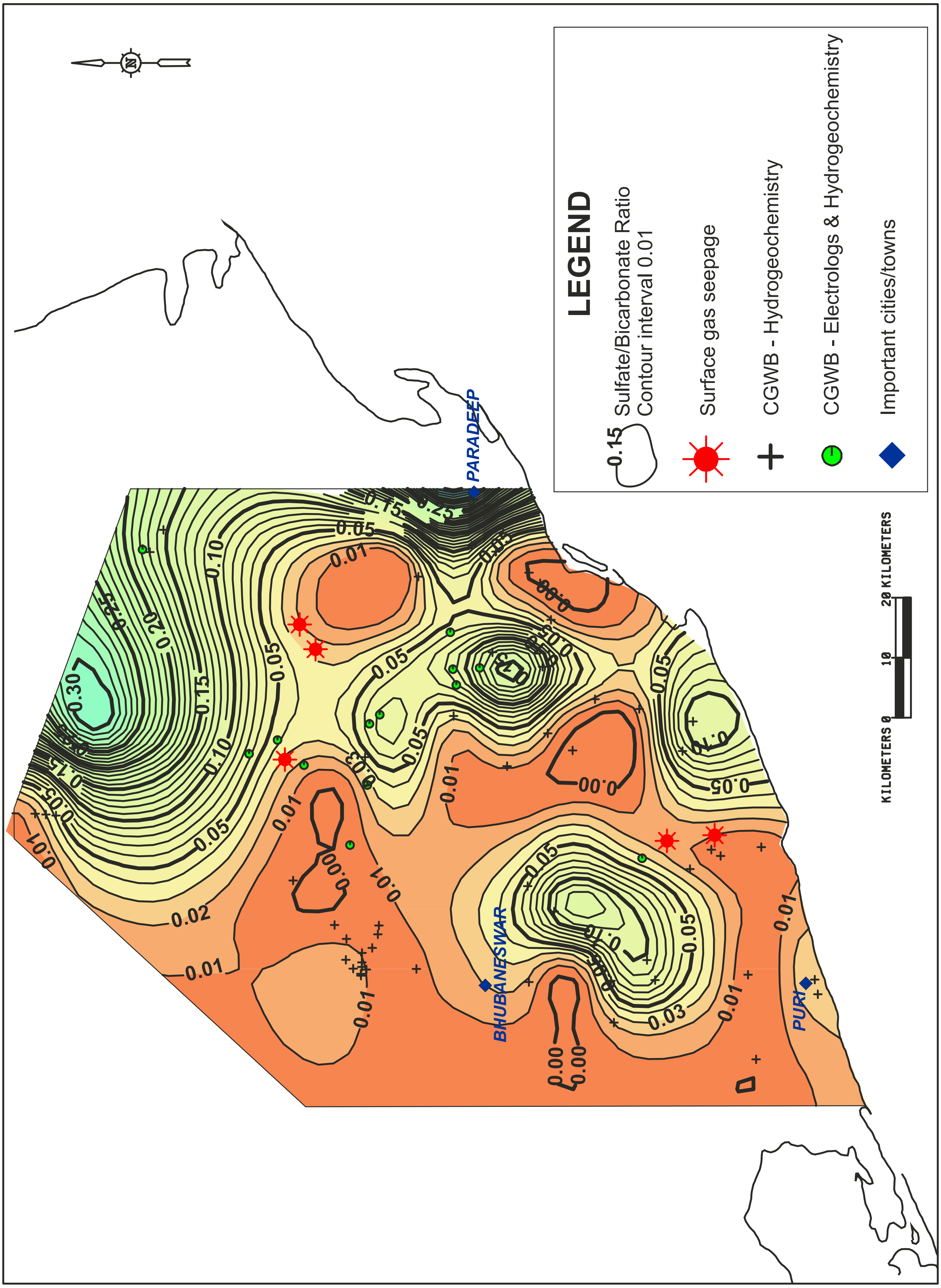

Fig. 9: Sulfate/bicarbonate ratio in the study area

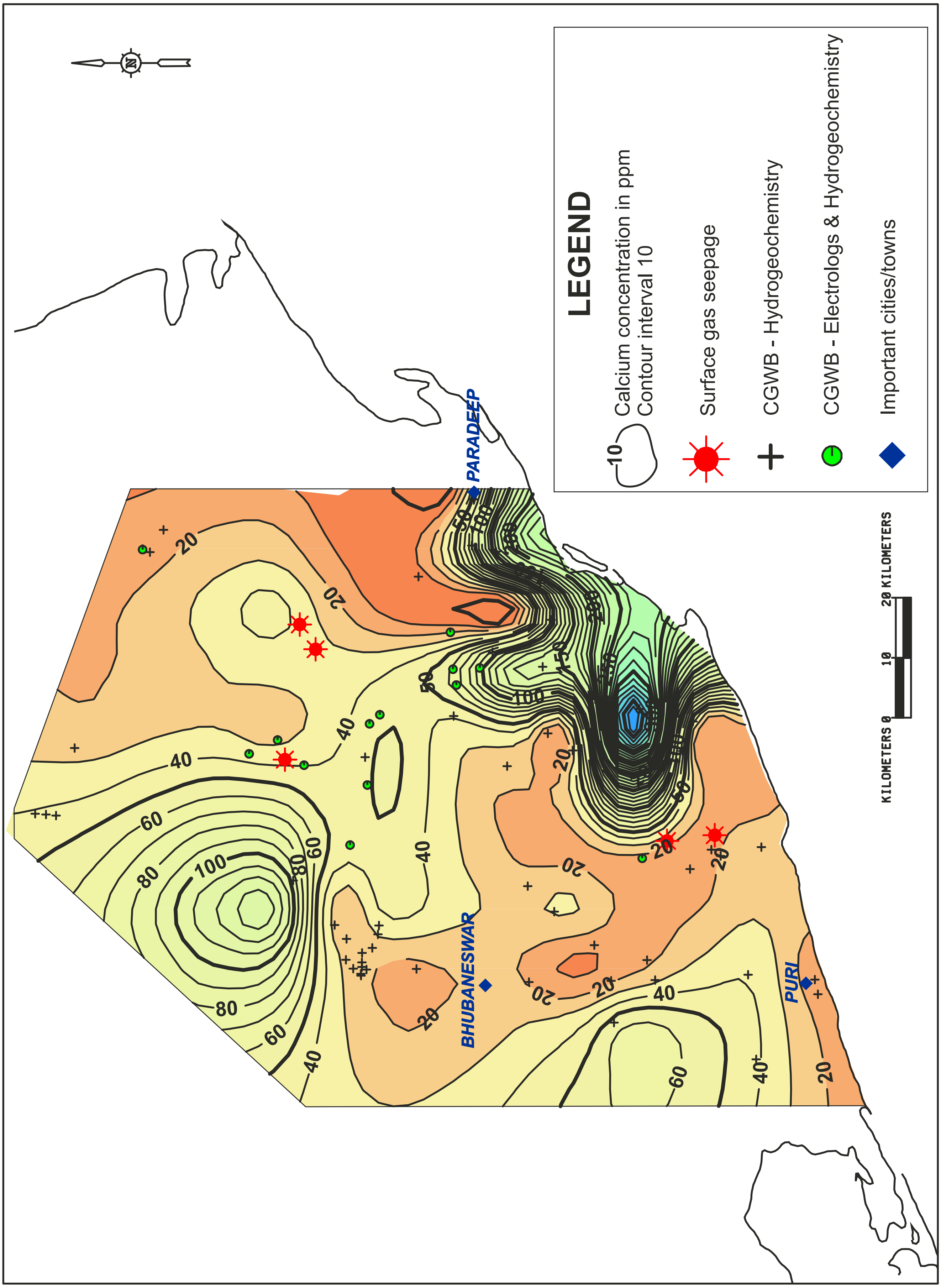

Fig. 10: Calcium concentration in the study area

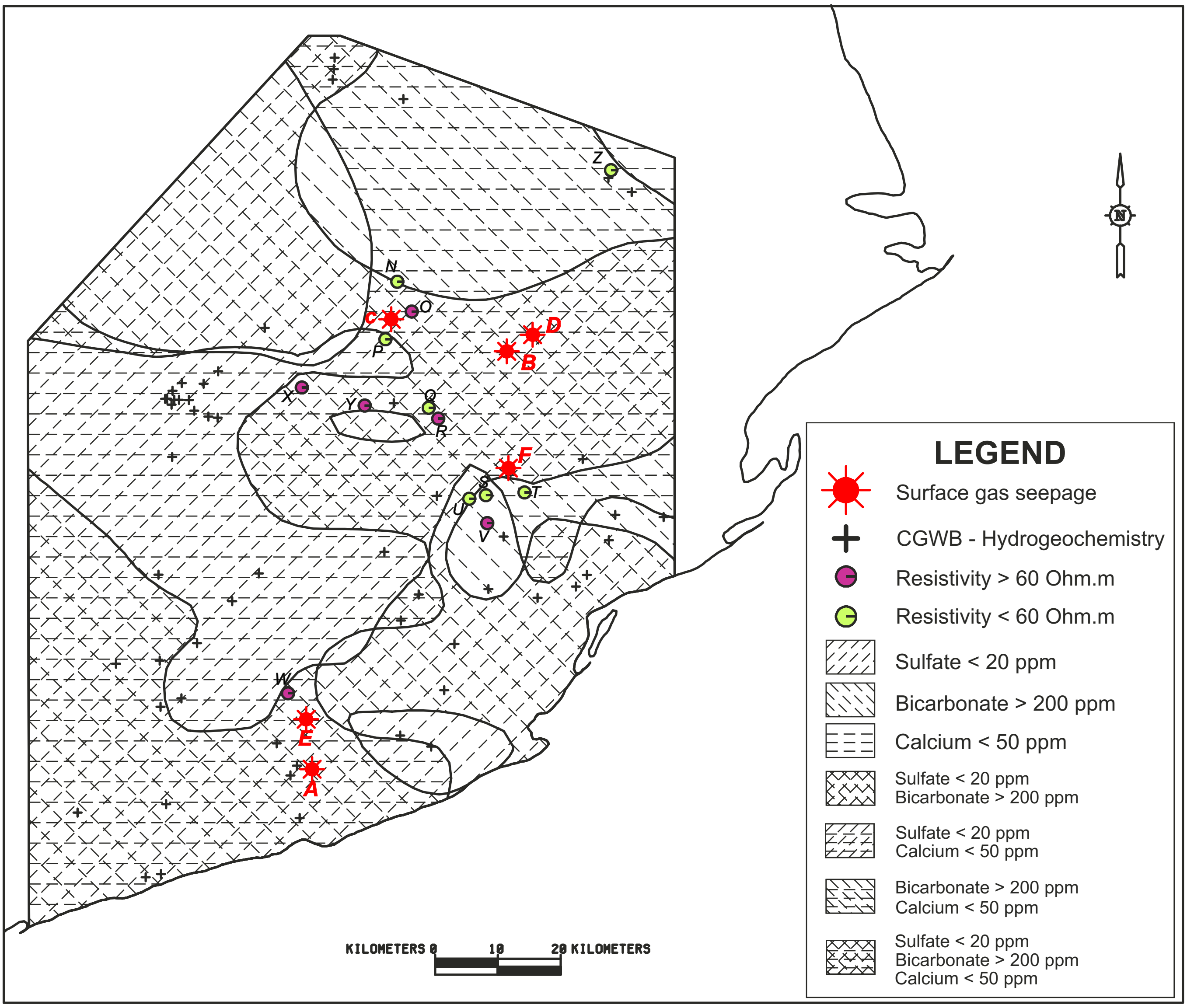

Fig. 11: Figure showing the areas covered by ionic concentrations of sulfate< 20 ppm, bicarbonate > 200 ppm and calcium < 50 ppm along with locations of gas seepage sites and CGWB-tube-wells.

further decreases towards the coastal area in the south from 0 to 0.01. Similarly, in the central portion of the study area it is also showing low value (0.01-0). It also shows a decreasing trend towards the interior and northern parts.

Calcium Concentration Map

From the calcium contour map of the Mahanadi on-land basin (Fig. 10), except for the southeast and northwest parts of the study area, the calcium concentration is lower than 50 ppm. Further, it can be noted that the calcium ion concentration is low ranging in between 20 ppm and 40 ppm at the gas seepages locations.

DISCUSSION AND CONCLUSIONS

The present study, based on the compositional and carbon isotope analysis, has established that the surface gas seepages occurring in the on-land Mahanadi basin are biogenic in nature (Tables 1 & 2). The significant lead regarding the correlation of normal resistivity curves with the gas bearing reservoirs has come from the normal resistivity value of the tube-well at “O” corresponding to the gas seepage depth of the location “C” (Fig. 3). The study of normal resistivity log curves of the CGWB BDRs suggest the minimum threshold value of resistivity of 60 ohm.masan indication for the possible presence of biogenic gas in the reservoir. Out of 13 tube-wells, 6 wells have displayed presence of reservoirs with resistivity greater than 60 ohm.m (Figs. 4 & 5). Further, the depth versus resistivity plot showed that the high resistivity zones range in depth from about 30 to 200m (Fig.6).

Formation waters associated with biogenic methane have a common chemical character that can be an exploration tool, regardless of formation lithology or age. Hydrogeological attributes associated with biogenic gas is invariably characterized by very low sulfate, calcium and magnesium and high bicarbonate ions concentration. The distinct geochemical signature associated with biogenic gas evolves through the processes of biochemical reduction of sulfate, enrichment of bicarbonate, and precipitation of calcium and magnesium ions (Van Voast, W.A., 2003). In the present study, the geochemical characteristics of the formation waters have shown the lower concentrations of sulfate and calcium, and higher concentration of bicarbonate (Figs. 7-10). Though it is not necessary that biogenic methane is always associated with such groundwater (Van Voast, W. A., 2003), this can indicate that the region is not unfavourable for the bacterial methanogenisis, which is already proved by the gas seepages at several locations.

An attempt has also been made to observe any correlation between the required ionic concentrations and the gas seepage sites and CGWB tube-well locations with positive indications. The Figure 11 shows a map with surface gas seepage locations, CGWB tube-well locations with resistivity greater than 60 ohm.m and locations with resistivity less than 60 ohm.m. Further, the areas having sulfate concentration less than 20 ppm, bicarbonate concentration more than 200 ppm and calcium concentration less than 50 ppm are indicated with different line hatching.

It can be seen from this figure that to the south of the study area, the gas seepage locations of “A” and “E”, and CGWB tube-well “W” which has reservoirs with resistivity more than 60 ohm.m, are falling in the area where the concentrations of the three ions are within the required range. To the north of the study area also, the gas seepage locations of “C”, “D” and “B”, the CGWB tube-wells of “O”, “X”, “Y”, “R” are falling in the area where the ionic concentrations are within the required range. Hence, it can be observed that the gas seepage locations and CGWB tube-wells with greater resistivity zones broadly fall within the areas that have supportive sulfate, bicarbonate and calcium concentration values. Only the CGWB tube-well at “V” located in the south central portion of the study area, which has presence of reservoirs greater than 60 ohm.m resistivity, has bicarbonate concentration within the range while having sulfate concentration greater than 20 ppm and calcium concentration greater than 50 ppm. In addition, it can be noted that other CGWB tube-well locations which do not have reservoirs with resistivity greater than 60 ohm.m fall inside or on the fringe of the area where the ionic concentrations are within the required range.

The foregoing observation suggests that, though the entire study area is conducive for biogenic methane genesis, only a few tube-wells have supporting evidence. It can also be observed that while higher resistivity that support biogenic gas charge can be found in some tube-wells near to the gas seepage locations, some other adjacent wells do not have such resistivity development. For example, near the gas seepage location of “C”, development of higher resistivity can be observed at “O”at the corresponding depth but not in other adjacent locations of “P” and "N”. Thus, it can be noted that biogenic gas may not be charged in a wide region and might be restricted to pockets of contiguous reservoir facies of few square kilometre area, in line with the facies development in the fluvial depositional environment. It may also suggest that the organic content of the shales and clays has local variations affecting the biogenic methane genesis. This brings forth the necessity for further detailed study including facies analysis, organic content analysis, surface geochemical sampling etc. Nevertheless, the approach employed in the present study has established a methodology where eletrologs and hydrogeochemical data of tube-wells drilled by groundwater agencies can be gainfully utilized to identify the biogenic gas bearing reservoirs in areas where gas seepages have been reported, with no extra cost. In tandem with other geological studies, the areal extent and depths of such pools can be established for commercial exploitation keeping in view the comparative lower costs involved in drilling and exploitation of shallow biogenic gas. The same approach can be extended as a reconnaitary tool for biogenic methane exploration to other alluvial terrains and river deltas of India where gas seepage is reported.

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