Geochemistry of Gas Seeps from Surface Shows and Wells of the Himalayan Foreland Basin

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Summary

Numerous gas seeps have been reported in the Himalayan foreland fold and thrust belt from time to time. Some gas seeps including the one at Himriganga are characterized as those of thermal origin, whereas some others are of bacterial origin. The gas seeps, in general, are characterized by high nitrogen concentration. On the other hand, gas shows in the wells, namely, JMI#â, Nurpur#á (both Dharamsala Formation) are methane rich with small nitrogen concentration and are dry gases of thermogenic origin (C_2+ < 2% in JMI#â). Carbon isotopic composition of methane in these wells suggests a deep overmature source for these gases ($\delta^{13}C_1$ ~ - 32.0‰).

Coals/carbonaceous shales within the underlying deeply buried Subathu are believed to be the probable source rocks for this gas as Dharamsala Formation has no source potential. The outcrop studies have also suggested poor organic matter richness and remaining hydrocarbon generation potential in samples representing different formations, however, the coals within Subathu exhibit better chance to have acted as source rock for gaseous hydrocarbons wherever they are developed in the subsurface.

The genesis of nitrogen and the factors controlling its distribution in natural gases are poorly understood. However, nitrogen may be an important component to define deeply buried humic (coaly) source rock or other overmature source rocks (e.g., Proterozoics). Such nitrogen rich gases are formed only in the final stage of gas generation after methane generation has practically ceased.

Though, commercial discovery of hydrocarbons has been elusive till date, exploratory efforts may be continued in view of the methane rich gas occurrences in some of the wells drilled in the basin. Chances of getting hydrocarbons are, however, more in the traps which remained undisturbed during different tectonic events in the basin.

Introduction

The Himalayan foreland fold and thrust belt has been under active exploration for hydrocarbons since the inception of ONGC in 1956 in the states of Jammu and Kashmir, Himachal Pradesh and Uttaranchal and a lot of geoscientific data have been generated. Evidence of a number of surface gas seepages, presence of non-commercial gas bearing horizons in a number of wells drilled in Jwalamukhi area; surface oil seepage from thin limestone band of Subathu sequence near Chomukha village in Sundernagar area (Himachal Pradesh) and asphalt shows in Subathu limestone at Satra, Jokan in Punchh area (J. K.), are documents of hydrocarbon generation potential of this basin. The most famous gas show is of the Jwalamukhi temple which mostly consists of methane (87%) with small amounts of CO_2, N_2 and O_2 (Mudiar and Shukla, 1991).

A number of wells in foothills and Punjab plains have been drilled; however, commercial hydrocarbon discovery has been elusive till date.

The present work is an overview of the geochemical studies carried out in the basin and particularly deals with the aspect of genetic characterization of natural gas seeps in the area.

Geology and tectonics

The Himalayan foreland fold-and-thrust belt (commonly known as Himalayan Foothills) is a part of north-west Himalaya which comprises sequences with long history of sedimentation and tectonics. The main structural elements of Himalayan foreland fold-and-thrust belt are MCT, MBT and HFT. The Main Central Thrust (MCT) separates the Higher Himalayan crystallines from the Lesser Himalayan clastics and metasediments. The Main Boundary Thrust (MBT) separates the lesser Himalayas from the Tertiary sediments (the foothills) in the south while the Himalayan Frontal Thrust (HFT) marks the southern limit of the foreland fold-and-thrust belt (Fig.1).

Main Boundary Thrust (MBT) is the most important thrust in the area. To the west of MBT, successively younger sediments of Tertiary age are generally repeated or eliminated due to thrusting. The area is characterized by elongated tight anticlines which are highly deformed by the numerous faults/thrusts. Thrusting resulted due to northward

Fig.1.

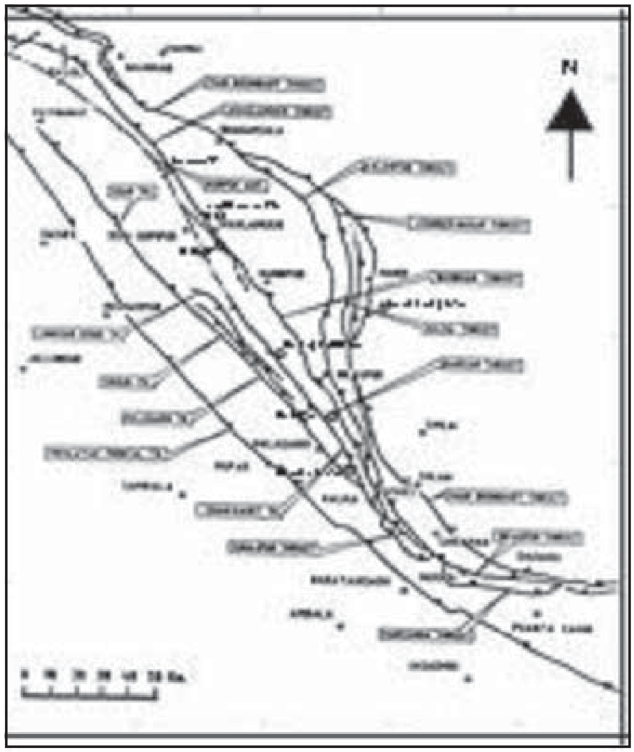

Fig.2.

movement of the Indian plate and its collision with the Eurasian plate during Tertiary times. In fact, Punjab Basin/ Himalayan Foothills/Himalayan Foreland is a poly tectonic history basin. The important tectonic episodes in the basin occurred during Late Eocene, Middle Miocene, Pliocene, Middle Pleistocene and Holocene (< 0.22 m.y., Singh et al., 1995). The tectonic map of northwest Himalayan foothills with some well locations is given in Fig. 2. The folded belt, in general, exposes sediments of both Pre-Tertiary and Tertiary ages. To the east of MBT only the Pre-Tertiary sediments are exposed. To the west of MBT early to Late Tertiary sediments (Subathu to Siwalik formation) have been mapped as linear to elongated bodies having N-S to NW-SE trend in a number of thrust blocks. Due to repeated thrusting, the older Pre-Tertiary formations are found exposed with the younger Tertiary sediments. The Pre-Tertiary sediments overlie the Archaean crystalline Basement with a pronounced unconformity. They are represented by Janauri Group and Mohand formation of Late Riphean age (Shukla et al., 1993). Huge thickness of sediments (with the presence of number of unconformities at different levels) is well documented within a series of thrust sheets and associated fold systems. The thickness of sediments varies from 4800-9500 m in Himachal Pradesh (Tandon et al., 1998).

Sedimentation over the area commenced under shallow marine conditions (Tethys sea, Subathu Formation), which gradually changed to fluvio-deltaic (Dharmsala Group) to fluvial (Siwalik Group) environment as a result of tectonic adjustment of rising Himalayas (Agrawal et al, 1998). The stratigraphic succession of the basin is given in Fig. 3 (Shukla et al., 1993).

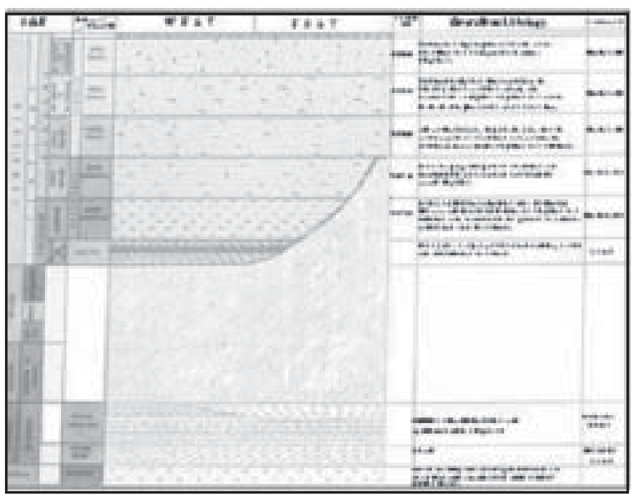

Fig. 3.

Source rock potential of the area

Source rock studies on the sediment samples encountered in drilled wells in the region have been carried out from time to time (Sain et al., 1987, 1989; Sain and Chopra, 1991; Gupta, 1999; Hasan et al., 2004; Goyal et al., 1989a, b). All these studies show very poor source rock potential of the formations drilled (Upper, Middle, Lower Siwaliks, Upper and Lower Dharamsala). Subathu formation (Upper Paleocene) has not been encountered in any of the drilled wells as it is deeply buried. However, as will be seen later, outcrop studies point out that Subathu formation deposited in shallow marine environment has some potential to have acted as the source of hydrocarbons in the area. Sundernagar#A which is the first well drilled east of MBT in the Proterozoics indicates poor generation potential of Proterozoic rocks also (Negi et al., 2004).

Outcrop Studies

A palynological source rock study of 230 outcrop samples of Subathu sediments of 21 traverses across J&K, Himachal and Uttaranchal was carried out by Misra et al. (1995). Their study points out that total organic matter recorded is poor in general and sediments are mature to highly mature (TAI 2.75 to 4.0). However, traverses in Kalakot Nala and Satra Nala in J&K and Khairi-Subathu show fair to good hydrocarbon source potential as they have good concentration of sapropelic-humic-semifusinitic organic matter. In another study on TAI of outcrop samples of Himachal Pradesh, Singh et al. (1995) observed somewhat lower maturation level for Subathu outcrops in the studied traverses (TAI 2.25-3.0). In an earlier study on redox and paleosalinity environments of deposition of Subathu outcrops (H.P.), Misra et al. (1981) using iron and manganese ratio, boron content and organic carbon content suggested that the Subathu sediments were deposited in marine environment, however, a major portion of the sample population indicates oxic conditions during deposition of sediments which also resulted in poor organic carbon content.

Source rock geochemical studies (through Rock Eval pyrolysis and total organic carbon analysis) on outcrops by Sain et al. (1990) from Himachal Pradesh reveal poor source rock potential in Subathu and Younger formations as the samples are found to be lean in organic carbon content with very low S_2 (Rock Eval pyrolysis parameter for remaining generation potential) values. Tiwari et al. (1991) carried out a comprehensive study on 574 outcrop samples from 36 traverses of Himalayan foothills from Himachal Pradesh and Jammu and Kashmir. Outcrop samples from Dharamsala, Subathu and Pre-Tertiary sediments were studied. Their study indicated that > 96 % of the samples were organically lean and only 21 samples (out of which 16 are from Subathu) have > 1 % organic carbon. Most of the organically lean samples have very poor hydrocarbon generation potential (S_2 is either zero or very small) in Tertiary as well Pre-Tertiary sediments. The organically rich Subathu samples are coals and carbonaceous shales. The organically richest coal sample (Subathu) of their study from Kalakot Nala traverse has following geochemical parameters: TOC (total organic carbon) = 80.33%, S_1 = 1.96 mg HC/g of rock, S_2 = 15.08 mg HC/g of rock, S_3 = 0.77 mg CO_2/g of rock, HI = 18 mg HC/g TOC, OI = 0.9 mg CO_2/g TOC, Tmax = 506 °C, and VRo = 1.37-1.84%. In organically rich samples Tmax values are high (³ 500 °C) and VRo values are also ³ 1.0% suggesting high levels of maturity. The carbonaceous shale samples of Subathu have much lower TOCs (1.08-9.35%) and remaining generation potential is also very low (S_2 = 0 - 2.4 mg HC/g of rock). Coals of their study although have higher S_2 values (2.14-23.82), they have very low Hydrogen Index values (10.2 – 61.0) indicating generation potential for some gaseous hydrocarbons only. The low values of HI may also be due to higher maturation level of these coals. Thus coals wherever developed in the subsurface may have acted as source of gaseous hydrocarbons in the basin. As the maturity of the coals is indicated to be high, the hydrocarbons generated by them earlier may have been lost due to various tectonic episodes in the basin. Chances of getting expelled hydrocarbons are more in the stratigraphic traps which remained undisturbed during different tectonic events in the basin.

Singh et al. (1995) have opined that the fossiliferous shale and limestone of Subathu (Paleocene) and Tal, Krol and Infra Krol (Precambrian to Cambrian) formations are the main contributors for the generation of hydrocarbons in this basin, provided sufficient overburden is there on the source rock. Bottom hole temperature of drilled wells gave indication that geothermal gradient in Himalayan foothills varies from 1.86°C to 1.98 °C/100 m. Therefore, Subathu and older source rock sediment will be mature to generate hydrocarbons in those areas only where overburden is more than 3 km thick. The presence of oil and gas shows in Inner and Medium tectonic belt favors this observation. However, majority of the samples of their study show low values of TOC, S_1, S_2 and HI indicating a Type-III, IV type of organic matter.

In a nutshell, source rock studies on the sediment samples encountered in drilled wells and on outcrops are not encouraging. The outcrop samples, in general, are poor in organic matter richness and remaining hydrocarbon generation potential except the coals within Subathu which exhibit better chance to have acted as source rock for gaseous hydrocarbons in the region.

Results and Discussion

Molecular and isotopic composition data of the gas seepages in the region, analysed in the laboratory from time to time, are presented in Tables 1 and 2. Gas data of well samples have also been included.

Himriganga Gas Seepage

The Himriganga gas seepage is near the Himriganga temple which is located about 6 km from Padhar on the Padhar-Diana Park-Balh Road. It is approximately 30km north of Mandi town in Himachal Pradesh. The gas seepage is occurring in a spring with gas escaping in the form of bubbles intermittently of variable intensity. The country rocks comprise of greenish grey traps of Mandi-Darla Volcanics Formation and the gas is escaping from several fractures observed in the traps. It is the first genuine hydrocarbon show across MBT (east of MBT) in the Lesser Himalayas as all other seepages observed till date are located south and west of MBT.

Himriganga gas seepage sample has been analysed several times in this laboratory. One such result is given in Table 1. Two other analyses on FID carried out earlier in the year 1999 have been given below (Sharma et al., 2000): Gas samples collected on Composition of hydrocarbons in ppm

Gas samples collected on	Composition of hydrocarbons in ppm							
	C_1	C_2	C_3	iC_4	nC_4	iC_5	nC_5	C_6+
14.08.1999 (I)	160	47	369	331	567	356	74	tr.
14.08.1999 (II)	1578	153	336	160	273	1037	53	tr.

It is evident from the above data that hydrocarbons up to hexanes have been detected in the Himriganga gas samples which point toward thermogenic origin of this gas. iC_4/nC_4 ratio is also < 1.0 which suggests a mature source of the hydrocarbons. However, hydrocarbons are present only at ppm level, therefore, carbon isotopic composition of methane could not be determined. One conspicuous feature of the gas is that it is highly enriched in nitrogen.

The source for gaseous hydrocarbons as observed in Himriganga may be from the deeply buried Paleogene Subathu sediments overlain by the thrusted Proterozoics or it might also have been contributed by the Proterozoic carbonaceous shales. In the latter case, the geothermal gradient is likely to have been enhanced considerably due to the abnormal thermal heating effect of the volcanic episode in this area. However, extremely low concentration of hydrocarbons in this nitrogen rich gas is not very encouraging from exploration point of view.

Jwalamukhi#-â (JMI#â) Gas

The first exploratory well in Jwalamukhi area (Jwalamukhi#A) was spudded in 1957 for structural and stratigraphic information and exploration of hydrocarbons in Jwalamukhi structure. The small gas find in two shallow zones (Siwaliks) of JMI#A well led to drilling of a number of wells in Jwalamukhi area to delineate its lateral extent and hydrocarbon prospects. So far 6 deep and 5 structural wells have been drilled in this area. No significant hydrocarbon occurrence was encountered in any of these wells except for minor indication of gas associated with water in Jwalamukhi#C and #F. The low production rate and low pressure in JMI#A suggests that the gas being produced may be seepage from some deeper horizons.

The well Jwalamukhi#â is the deepest well in the basin drilled to a depth of 6720m and terminated within Lower Dharmsala. The gas seepages observed in cellar pit of well JMI#â probably come from the interval 4031-4037 m in Lower Dharamsala. The zone was over pressured and not covered with cementation (Mudiar and Shukla, 1991).

Dominantly argillaceous lower Dharmsala Formation in JMI#â has indicated a maximum value of VRo around 0.49%, Tmax in the range of 425-441^{o}C and TAI values between 2.5-2.75, which suggest that the Lower part of Dharamsala Group has reached an early stage of maturation (Tandon et al., 1998).

The data of JMI#â cellar pit leakage gas collected from time to time have been presented in Table 1. The gas is enriched in methane and C_2+ hydrocarbons are present in a very low concentration and nitrogen concentration is also not high. There is similarity in the carbon isotopic compositions of methane in all the samples analysed from time to time. The 1978 sample was analysed at BGR, Hannover, Germany. The methane carbon isotopic value of Jwalamukhi gas at ~ -32.0 ‰ and dryness of the gas suggests a deeper overmature source for this gas. Another gas sample from a well in Himalayan foothills for which isotopic data is available is from Nurpur#á, which also has a similar methane ä^{13}C value of -32.5 ‰, suggesting genetic correlation with the JMI#â gas. Balh #á gas is also methane rich; however, its methane isotope value is not available to point out its origin. The Jwalamukhi gas methane isotopic data has been plotted on the generalized scheme of the organic matter evolution given by Schoell, 1983 (Figure 4).

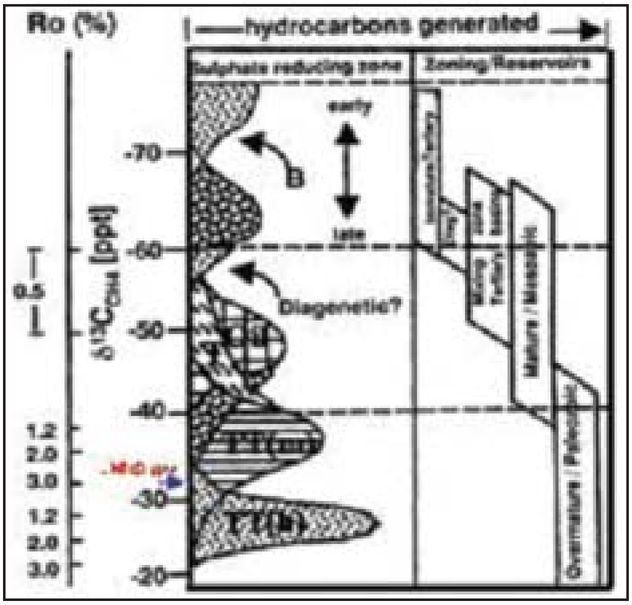

Fig.8.

Other Gas Seeps

A striking feature of the data in Tables 1 and 2 is that majority of gas seeps in the region have high nitrogen concentration. The relative concentration of methane and nitrogen in Himalayan Foredeep gas shows has been plotted in Figure 5.

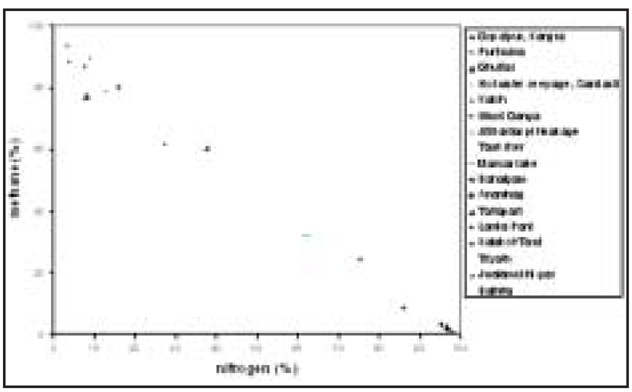

Fig. 9.

The genesis of nitrogen and the factors controlling its distribution in natural gases are poorly understood. Nitrogen is a common constituent in natural gases, particularly in red beds and from humic source rocks (Hunt, 1996).

Three possible sources are believed responsible for generation of the N_2 fraction:

(1) release of nitrogen bearing groups from organic matter, (2) release of ammonia from clays at elevated temperatures, and (3) influx of mantle nitrogen. In some cases, atmospheric nitrogen and dissolved meteoric nitrogen may also be important sources (Coveney et al., 1987). According to Waples (1985), nitrogen is thought to be an indicator of high levels of maturity formed primarily by metagenetic transformation of organic nitrogen and ammonia. Whiticar (1994) also suggests that nitrogen may be an important component to define deeply buried humic (coaly) source rock or other overmature source rocks.

Coal beds can give off as much as 20 litres N_2 (as NH_3)/kg of coal during maturation from bituminous to anthracite stages. The pyrolysis of coals by Klein and Juntgen (1972) indicated that nitrogen was released in two peaks, the first around 100°C and the second about 200°C.

A large percentage of the nitrogen in proteinaceous organic matter is converted to ammonia (NH_3), which dissolves in pore waters and is adsorbed by clays in the diagenetic stage. Part of this dissolved and adsorbed ammonia is believed to be converted to nitrogen during burial through contact with heavy metal oxides or meteoric water carrying oxygen (Hunt, 1979).

Lutz et al. (1975) attributed the high nitrogen gases in the red beds of the Rotliegendes formation to the thermal alteration of underlying Carboniferous coal measures and the dispersed organic matter in shales. When it contacts the red beds, the ammonia formed oxidizes to nitrogen. Incidentally, in Himalayan foothills very thick red beds are found in the Dharmasala Formation in the subsurface and are even exposed at the surface at different places, e.g., one can see them by the road side of Nahan-Sarahan-Simla highway. Thus, an organic source as above is the most likely source of nitrogen in this basin.

Laboratory measurements on Carboniferous coal measures of different types and rank have yielded kinetic data on the formation of methane and nitrogen from coals which support the hypothesis that fractional generation of methane and nitrogen leads to phases of preferential and even exclusive nitrogen generation in deeply buried sedimentary basins (Krooss et al. 1995). The onset of nitrogen generation from coals in geologic systems occurs between 200 and 250°C and N_2 becomes the major gas component at temperatures above 300°C. Nitrogen rich gases are thus formed only in the final stage of gas generation after methane generation has practically ceased.

In the outcrop samples of Subathu Formation in Jammu and Himachal Pradesh, highly mature to overmature coal seams have been reported on the basis of TAI studies (TAI, 3.5-4.0) (Misra et al., 1995) and source rock studies (Tmax > 500°C and Ro ³ 1.0 %, Tiwari et al., 1991). Thus coals within Subathu may have contributed toward nitrogen generation in the basin. However, the major source may be the organic matter in the deeply buried overmature Proterozoic rocks. Some contribution from other sources of nitrogen can not be totally ruled out.

From Table 1, it can be observed that few gas seeps, namely, at Punjwana; at village Jambal, and at village Kaloh in the region are of bacterial origin. These seeps are rich in methane and their carbon isotopic compositions are in bacterial range. The gas show at Jambal village is possibly generated through the bacterial fermentation of organic matter which is usually the generation mechanism of bacterial methane in terrestrial (fresh water) environments, as the high concentration of CO_2 and carbon isotopic composition of this CO_2 (-5.0 ‰) support the generation of methane through above mechanism (Faber et al., 1992).

$$CH_3COOH ® CO_2 + CH_4$$

Other gas shows in the region, namely, gas show near Gopalpur, distt. Kangra; from Lower Murres, Tawi river; and from warm water spring near Triyath village are undisputedly of thermogenic origin based on their C_2+ concentration, C_1/C_2+C_3 ratio and carbon isotopic composition of methane. For some gases, since $d^{13}C$ values of their methane and associated CO_2 are not available, it is difficult to pinpoint their origin (thermogenic/bacterial) with certainty.

Conclusions

Numerous gas seeps have been reported in the Himalayan foreland fold and thrust belt from time to time. Some gas seeps including the one at Himriganga are characterized as those of thermal origin, whereas some others are of bacterial origin. The gas seeps, in general, are characterized by high nitrogen concentration. On the other hand, gas shows in the wells, namely, JMI#â, Nurpur#á (both Dharamsala Formation) are methane rich with small nitrogen concentration and are of thermogenic origin. Similarity in the isotopic and chemical composition of gases in Jwalamukhi#â and Nurpur#á suggests their genetic correlation. An isotopic composition of methane at ~ -32.0 ‰ in these wells suggests a deep overmature source for this gas. Coals/carbonaceous shales within the underlying deeply buried Subathu may be the probable source rock for this gas as Dharamsala Formation has no source potential and outcrop studies have also suggested that coals within Subathu may have acted as source of hydrocarbons in the basin wherever they are developed in the subsurface.

Though nitrogen may have many origins, high nitrogen concentration in this basin may be due to deeply buried humic (coaly) source rocks in Subathu or other overmature source rocks (Proterozoics). Such nitrogen rich gases are formed only in the final stage of gas generation after methane generation has practically ceased. As this basin encountered several tectonic events, chances of getting hydrocarbons are more in the stratigraphic traps which remained undisturbed during different tectonic episodes in the basin.

Although, commercial discovery of hydrocarbons has been elusive till date, exploratory efforts may be continued in view of the methane rich gas shows in some of the wells (Jwalamukhi wells, Nurpur # á, and Balh # á) drilled in the area.

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