

Basin Centered Gas Accumulation (BCGA) as a Significant Future Gas Source in India

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Summary

As the demand for Natural Gas in India increases, explorationists will be required to put in place new concepts to establish fresh sources of supply, including unconventional gas. Basin Centered Gas Accumulation (BCGA) is one of the unconventional sources, which has vast potential in India, as there are conclusive evidences of this pervasive accumulation in Cambay basin, Krishna-Godavari basin and Cauvery basin, as deduced from the drilled well information.

Introduction

All over the world, focus is being shifted from oil to natural gas. High oil prices, high investment for getting additional oil, relative abundance of gas and environmental considerations have made most of the countries shift their focus towards gas. Though till 2003, we were meeting demand on our own through indigenous production, it is now turning difficult to meet the demand which is increasing annually @ 4.3% per year. In addition to the efforts for augmenting gas production from the conventional gas pools, we have to simultaneously concentrate on the unconventional resources to augment the production to meet the burgeoning demand for natural gas.

Natural gas from unconventional sources is playing a significant role in the supply mix of natural gas in the developed nations like USA. Supply from unconventional sources accounted for 32% of the total gas production of USA in the year 2002, (EIA, 2004). Coal Bed Methane, Basin Centered gas, Gas shales and UCG are increasingly important components in the unconventional natural gas supply as traditional sources of gas continue to decline. With vast amount of unconventional gas resources and their contribution to the ever increasing energy demand, it is of utmost importance to the exploration geoscientists to expand upon long-held traditional concepts and effectively open up new frontiers.

In India, considerable progress has been made to tap unconventional sources of gas like Coal Bed Methane (CBM) and gas hydrate. Analysis of the available data suggests high potential for the Basin centered Gas Accumulation (BCGA) in various sedimentary basins of

India. This paper attempts to discuss the potential of BCGA and approach for its effective exploration.

Unconventional Natural Gas Resources

There are various definitions of an unconventional gas system. In the earlier days, the distinction between conventional and unconventional was primarily based on economic considerations, with marginally economic gas resources like coal-bed methane and low permeability tight gas being termed as unconventional. But apart from the economic aspect, there is an important geologic consideration that distinguishes the two. Whereas conventional gas resources are essentially buoyancy-driven deposits occurring in structural and/or stratigraphic traps, unconventional deposits are not generally buoyancy driven. They are mostly independent of structural or stratigraphic traps and occur as regionally pervasive accumulations (Law, 2002).

Basin-Centered-Gas-Accumulation (BCGA)

These are regionally pervasive unconventional resources of natural gas encompassing very large area and may occur as single, isolated reservoirs or as multiple, stacked reservoirs (Fig.1). Over the years they have gained importance as one of the economic resources. The exploration and production from BCGAs is mainly confined to North America, where the stratigraphic distribution extends from Cambrian through Eocene. As per USGS estimates, the in-place Gas resources of basin centered gas accumulations in United states amounts to 6788 Tcf (Recoverable component of 223 Tcf). About 15% of natural gas production in USA is contributed by deep basin gas



reservoirs (Law, 2002) which are next to Conventional Natural Gas contributing 77% of total gas production.

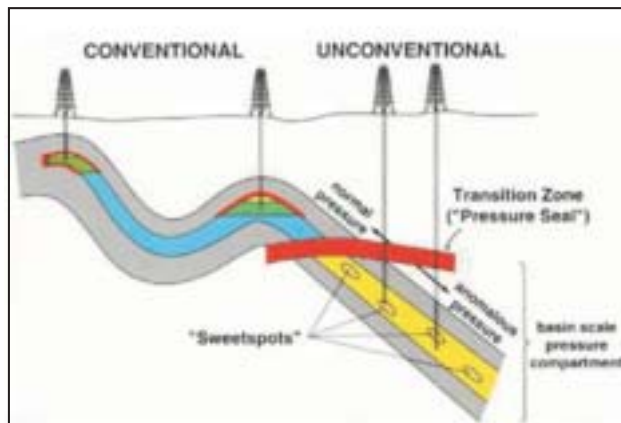


Fig.1: Conceptual model for basin-center anomalously pressured gas accumulations.

Key Elements

- (1) The regional pressure seal expressed as a sonic or seismic velocity inversion (e.g., regional boundary that separates normally pressured rocks above from anomalously pressured rocks below), and
- (2) Production sweet-spots below the regional pressure seal (e.g., domains characterized by enhanced porosity and permeability). Blue is fluid that is dominantly water (simple phase); yellow is fluid containing a significant free gas phase (multiphase) and red are capillary seals. (Source: Shirley, 1999)

Basin centered gas accumulations begin when inter-bedded sand and shale layers are buried in subsiding sedimentary basins. The resulting heating of organic matter in the shales generates large volume of gas while compaction and alteration reduces the permeability of the inter-bedded sandstones such that gas cannot easily migrate to shallower levels.

The inherent lenticularity of the sandstone present in these sand-shale layers also helps limit the movement of the gas. Generation of the gas at rates faster than it can escape leads to the expulsion of the formation water and, commonly, the over-pressuring of the reservoirs. Because the gas cannot freely migrate up into the conventional reservoirs along the shallower basin fringes, these up dip units often contain abundant water. So the accumulations are not reservoir specific but encompass large volume of strata in a manner governed by the burial, thermal and diagenetic history of the basin.

Some of the more important distinguishing

characteristics of BCGAs include abnormal pressures (over- or under-pressured), low permeability reservoirs, and a general absence of downdip water.

There are two types of BCGAs, 'direct' type and 'indirect' type. The two types are distinguished on the basis of source rock quality; a direct BCGA has a gas prone source rock and an indirect BCGA has an oil prone source rock. There may, however, be a hybrid system as well.

Exploration Strategy for BCGA

The exploration strategy for BCGAs can be viewed as a four step process, involving

- i) **Reconnaissance phase**, where identification of basins suitable for BCGA exploration is carried out. Identification of source rock and its type, existence of reservoir and its quality, exploration history of the basin, if available, form the critical parameters in this phase.
- ii) **Confirmation phase** entails determination of reservoir pressure, since most BCGAs are abnormally pressured. It is also important at this stage to ascertain the mechanism of abnormal pressure, where the composition of pore fluid can be a guiding factor, as in direct as well as indirect BCGAs the pore fluid is essentially gas with little or no water.
- iii) In the **delineation phase**, the vertical and areal distribution of the accumulation is mapped on the basis of pressure data or thermal maturity values.
- iv) Though most of the BCGAs are not commercially productive over the entire basin, areas of good reservoir properties (**sweet spots**) can be identified (fig.2), which may be structural or stratigraphic in nature and always occur within the abnormal pressure envelope. In most of the cases they occur near the upper boundary of the BCGA.

Institute for Energy Research, Gas Research Institute and the DOE, USA undertook a study of the pressure compartmentalization of deep gas and came out with a methodology to gain an understanding of the processes controlling the gas accumulations.

These methods give operators the ability to determine the position of the regional pressure boundary and allow for evaluation of the 3-D aspects of the pressure boundary surface, with special emphasis on areas characterized by positive relief.

The techniques mainly involve using well log and

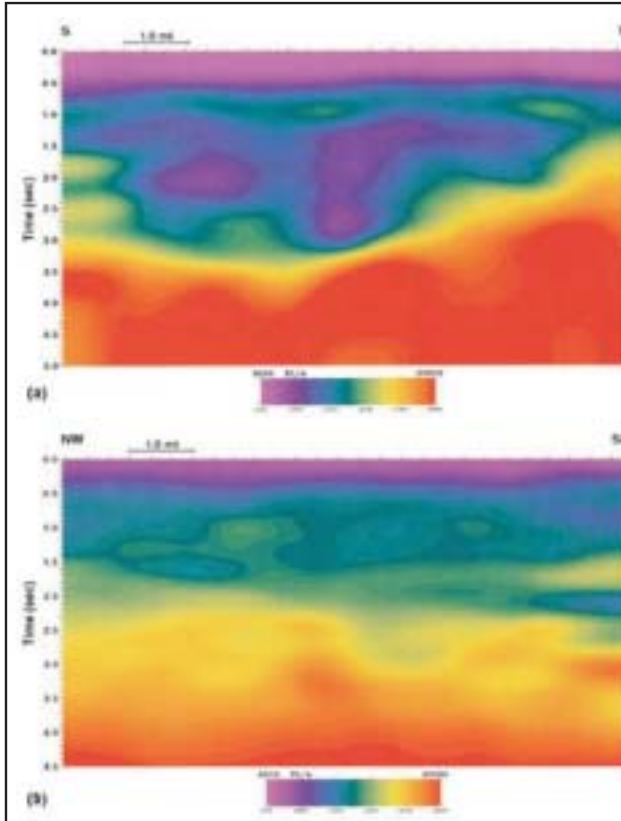


Fig.2. Two-dimensional seismic interval velocity fields constructed from seismic lines in the Wind River Basin. In profile A the anomalously slow velocity domains represent commercial gas accumulations. In contrast, in B there are no significant velocity anomalies, and hence no exploration leads with respect to basin center gas accumulations. (Source: Shirley, 1999)

seismic data to create visualizations that can give an idea of what is happening in the subsurface. The position of the pressure boundary is determined first by establishing a velocity anomaly in individual wells using sonic logs (fig.3). The depth of the onset of the velocity inversion indicates the pressure boundary and the top of an anomalously pressured compartment.

In most of such basins, drilled wells may be sparse or irregularly spaced leaving well log data gaps. Seismic interval velocities can be used to greatly reduce this interpolation distance, thereby significantly improving spatial sampling. Velocity inversion is seen on both sonic well logs and seismic data, but well data provide independent subsurface measurements and can best identify the cause of the inversion. Therefore, well data are used to constrain the interpretation of the seismic velocities.

The 2-D and 3-D models created using these data are then used to help establish which depositional facies

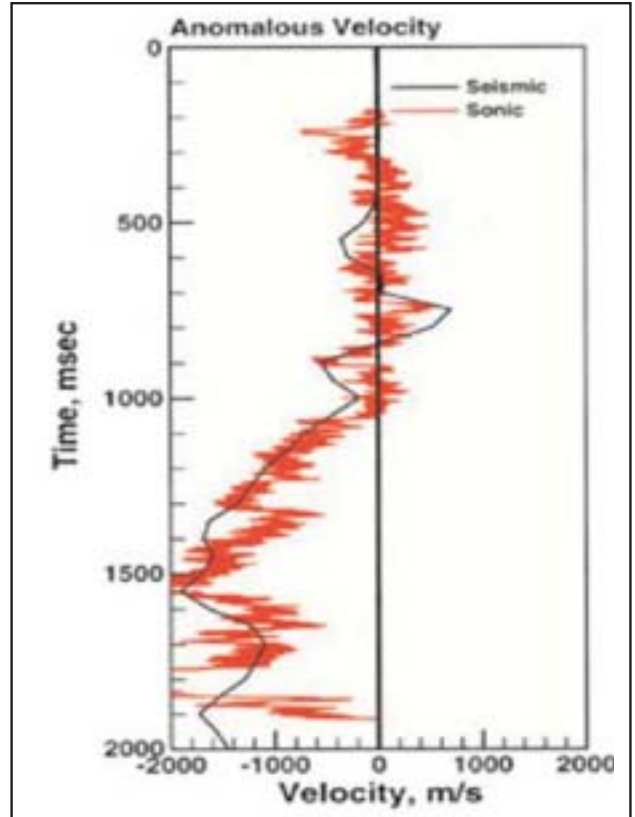


Fig.3. Sonic and seismic interval velocity-depth profiles from a coincident well log and seismic line CDP (Source: Shirley, 1999)

below the pressure boundary constitute porosity and permeability “sweet spots.”

Areas of locally extreme seismic velocity inversions are observed between wells and in wildcat settings in two and three dimensions corresponding to porosity and permeability ‘sweet spots’ below the pressure boundary.

Potential of BCGA in India

Considering the habitat of BCGA as depicted above, several sectors in the sedimentary basins in India are considered to hold promise for exploration of this unconventional gas source. The geoscientific data from wells drilled in Cambay, Krishna-Godavari and Cauvery basins conclusively point to the presence of BCGA. The following sectors are considered to be immediate candidates for exploration of BCGA:

- Cambay: North Cambay for direct BCGA and south Cambay for indirect type.
- Krishna-Godavari: Kommugudem-Mandapeta sector for direct BCGA
- Cauvery: Ariyalur-Pondichery for direct BCGA.

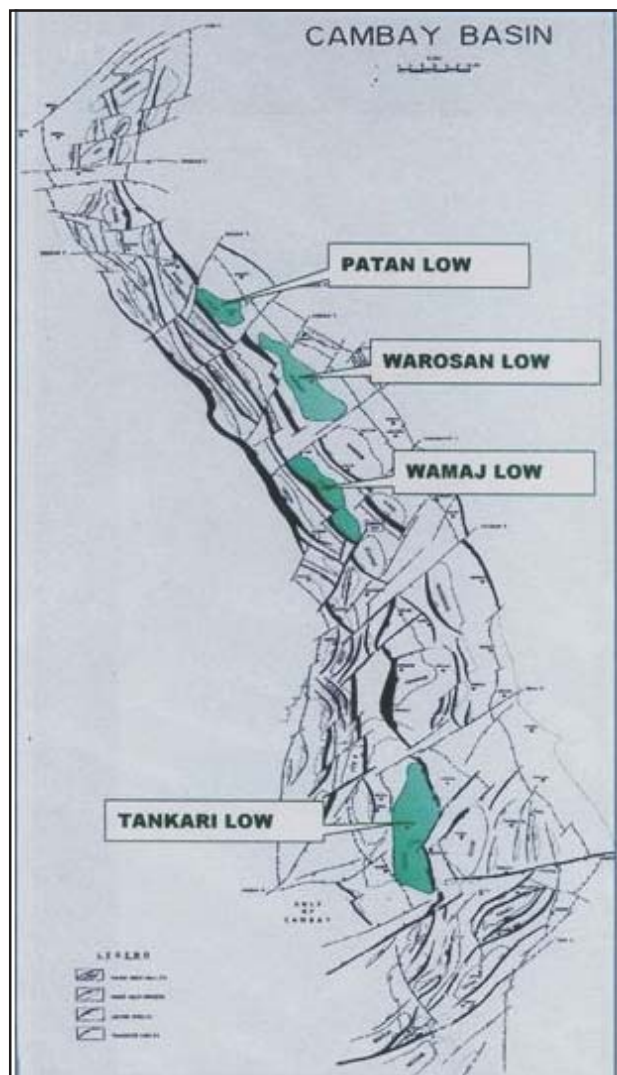


Fig. 4. Tectonic map of Cambay basin showing the prominent 'Lows'

Cambay Basin is a long, narrow intra-cratonic rift basin comprising of a number of grabens and half grabens formed by rifting during early Tertiary period (fig.4). Deccan basalts of Upper Cretaceous to Lower Paleocene age form the technical basement which is overlain by Olpad Formation deposited in continental to lacustrine setting. Olpad sediments mainly comprise of volcanic conglomerates, silt, shale and claystone derived from Deccan Trap. The overlying Cambay Shale Formation marks the first marine transgression in the basin during Early- to Mid-Eocene. This Formation is sub-divided into two Members separated by an unconformity.

The deepest well drilled in one of the prominent 'Lows' of the basin, Wamaj Low is well 'A', which was drilled to a depth of 4498m and was terminated in Olpad

Formation. Five objects were identified within Olpad section of which four were be tested. As per the geochemical studies carried out in this well, Olpad section has excellent source rock potential with TOC varying from 0.21 to 21% and average HI values from 83 to 219 indicating type III kerogen. Moreover, a continuous increase in total gas in the out-coming mud was observed in the well 'A' while drilling from 3420m to 4498m (Fig.5) with increasing amount in the deeper section clearly indicating presence of gas in the lower part. The gas consists mainly of methane with minor ethane at places ranging from 0.2% to 7% (total gas maximum 10%). As depicted by free gas analysis and composition diagrams, it is a dry gas and is not associated with oil. This well incidentally was not located in the deepest part of the low but was drilled near the eastern flank.

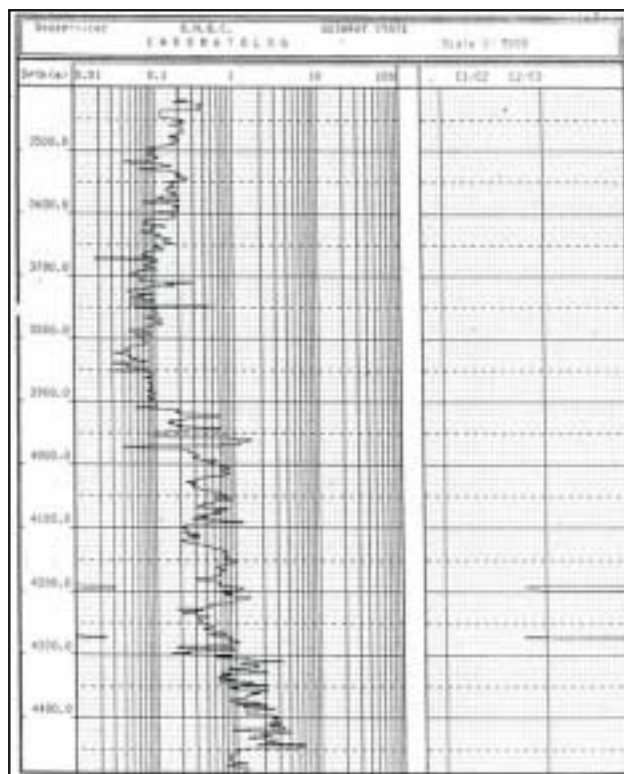


Fig.5. Increasing Total gas with depth in the well-A

From d-exponent plots, it is evident that over-pressure was also encountered during drilling of well A which is another indication of a BCGA set-up. From 1600m downwards there was a constant increase in pore pressure and the well gave a kick at a depth of 2400m where mud weight had to be increased to control the kick. As per the genetic modeling studies of Cambay Basin (Ray et.al. 2001) Olpad Formation in the Basin has generated 29 billion tonnes of O+OEG. The major depocentres where Olpad has generated hydrocarbons are Wamaj, Warosan, Broach, Patan

and Tarapur Lows. In the Wamaj sector alone, Olpad Formation is expected to have generated 348.82 MMt of oil and 740.34 billion cubic metre of gas. The expelled hydrocarbons had probably very little scope to migrate across the overlying Cambay shale and are expected to have got accumulated in the reservoir facies within Olpad and Cambay Shale Formations.

The pre-requisite for direct type of BCGA is a Type-III source rock and the proximity of reservoir rock to the source. The Olpad Formation with its Type-III organic matter has generated enough hydrocarbons. Olpad Formation comprising of lithic sandstone, lithic siltstone, deposited in the alluvial fan complex is likely to possess reservoir properties which has been seen in the well A. This low porous and permeable reservoir may accumulate gas ranging from a few metres to hundred metres without any downdip water. The generation of hydrocarbons from source rock in the case of BCGA occurs at thermal maturity exceeding 0.6% Ro. The geochemical studies indicate that Olpad Formation as sampled in this well has attained maturity value above 0.6% to generate gaseous hydrocarbons.

The Krishna-Godavari basin in the East Coast of India is a pericratonic polyhistory basin. Wells drilled in Kommugudem-Mandapeta sector of this basin have indicated high pressure, low permeability sands in Gondwana sequences with continuous gas shows while drilling. In one of the well 'B', drilled in the basinal part, continuous gas shows ranging from 5 to upto 50% of total gas has been observed while drilling through the Permo-Triassic and Lower Gondwana sequences. According to the source rock studies of the well, the Permo-Carboniferous sequences are having good source potential with average Tmax of 476° and average TOC 12.8%. The Cauvery Basin, also in the east coast of India, is a pericratonic basin with sediments ranging in age from Jurassic to Recent. The Ariyalur-Pondicherry sector of Cauvery basin, which has a thick deposit of sandstones within lower part of upper Cretaceous, can emerge as another suitable candidate for BCGA as evident from the information obtained from the drilled wells. Continuous gas shows ranging from 12% to as high as 77% of total gas has been reported while drilling through this formation in 'C', one of the wells drilled here. The sands have a typical low permeability ranging from .007 to 2.49 md and porosity in the order of 6 to 9.5 %. High formation pressures in the range of 70% more than hydrostatic have been reported at two intervals in the well. Geochemical studies in the well suggest that the Cretaceous fine grained sediments have very good organic matter richness with TOC

ranging from 0.79-5.4%. They have good source rock potential for gas and gas condensates. The hydrogen index values are less than 160 indicating Type III kerogen, a prerequisite for direct type BCGA. The Tmax value from 2200m (437°) to drilled depth beyond 4700m (453°) puts the Cretaceous sediment in hydrocarbon generation zone. These three sectors, therefore, may form immediate targets for exploration of BCGA

Conclusion

Exploration for BCGA in India is only in the early reconnaissance stage and has a long way to go. Several sectors in the sedimentary basins of India are considered prospective for BCGA. Though some inroads have been made in the exploration of other areas of unconventional gas resources namely, CBM, Gas hydrate etc., nothing significant has really happened to tap these resources. With oil price remaining at an all-time high and known reserves dwindling, it is time to use the known concepts and by now developed technologies to go full-fledged for BCGA exploration.

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