WELL DRILLING AND REVISED SUBSURFACE MAPPING YIELD NEW INSIGHTS ON TITAS GAS FIELD.

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Abstract Several studies to estimate the total reserve of the Titas gas field, located approximately 50 miles east of Dhaka City in east central Bangladesh, have been undertaken in the past with inconclusive results. Recently drilled development wells have revealed startling new information. With this data, a better reserve estimate has been performed to determine the gas in place (GIP). With information from the newly drilled wells, revised subsurface maps have been constructed. New reserve estimation finds considerable additional gas in place in Titas gas field as opposed to the long-standing officially declared figure of the reserve.

ACRONYMS

BGFCL Bangladesh Gas Field Company Limited
GL   Ground Level
GIP   Gas in Place
IKM   Intercomp-Kanata Management Ltd
KB   Kelly Bushing
MSL   Mean Sea Level
MD   Measured Depth
ONGC   Oil and Natural Gas Company
TVD   True Vertical Depth

NOMENCLATURE

B_{gi} Gas Formation Volume Factor at Initial Reservoir Pressure
h_n Net Reservoir Height
h_g Gross Reservoir Height
S_{wi} Initial Water Saturation
ϕ Porosity

INTRODUCTION

Titas gas field was discovered by Pakistan Shell Oil Company (PSOC), with the drilling of the well T 1 in 1962. Until 1990, a total of eleven wells were drilled in four locations. During 1999-2000, three new wells were drilled from the location five.

Three gas sand groups (A, B and C sands) have been identified in the Titas gas formation. Sand A represents the highest rank formation encountered by the existing wells and account for approximately 80 percent of the total field reserves. Eleven wells have been drilled through A sand. Eight wells (T 1 through T 7 and T 11) are producing gas from this sand. The new wells (T 12, T 13 and T 14) that penetrated A sand have not started production yet. Generally, the reservoir properties of the

sand B and C are noticeably inferior to that of the sand A. Only three wells (T 8, T 9 and T 10) are producing gas from the B and C sands.

Subsurface geological maps are an interpretation based on limited data. It is the most important vehicle used to explore for undiscovered hydrocarbons and to develop proven hydrocarbon reserves. Subsurface maps of A sand have been revised in this study. B and C sand groups were ignored because of their less significant contribution to the total reserve and production.

METHODS OF CONTOURING

Any subsurface map is subject to individual interpretation. The amount of data, the areal extent of that data, and the purpose for which a map is being prepared, may dictate the use of a specific method of contouring. Tearpock and Bischke (1991) considered four distinct methods of contouring that are commonly used. These methods are: (1) mechanical, (2) equal spaced, (3) parallel, and (4) interpretive. In this study, interpretive contouring method is used to create the subsurface maps. In this method of contouring, the geologist has extreme geologic license to prepare a map to reflect the best interpretation of the area of study, while honoring the available control points. No assumptions, such as constant bed dip or parallelism of contours, are made when using this method. Therefore, the geologist can use experience, imagination, and ability to think in three dimensions and an understanding of the structural and depositional style in the geologic region being worked to develop a realistic interpretation. Tearpock and Bischke (1991) stated that interpretive contouring was the most acceptable and the most commonly used method of contouring.

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REGIONAL SETTING OF RESERVOIR

Sand group A consists of four sands (A1, A2, A3 and A4). Sand A1 is considered as minor sand. Three major gas sands (A2, A3 and A4) are discussed separately

Reservoir Properties of the sands A2, A3 and A4

According to Shell core analysis data (IKM Geological, Geophysical and Petrophysical Report, 1991) from well T 2 the porosity and permeability of A2 sand are 22 percent and 200 mD respectively. A water saturation of about 25 percent of 25000-ppm connate salinity was reported from oil base core measurements. The deepest level to which the sand A2 has been drilled is 9079 ft sub sea. No gas-water contact (GWC) was encountered in the A2 sand in any well. Reservoir thickness (top, base, gross and net) are presented in Table 1(end of paper).

According to Shell core analysis data (IKM Geological, Geophysical and Petrophysical Report, 1991) of well T 2 the porosity and permeability of A3 sand are 20 percent and 250 mD (median range 60 – 600). Average water saturation from an oil base core data is 33 percent No GWC was encountered in the sand A3 in any of the wells. A3 sand was drilled to 9223 ft at the deepest level. Formation top, base, gross and net sand from Oil and Natural Gas Company (ONGC, 2000) is listed in Table 2(end of paper).

A4 sand have porosity and permeabity of 20% and 150 md (median range 50 – 560) respectively. Among the three sands, Shell (IKM Geological, Geophysical and Petrophysical Report, 1991) reported a consistent higher percentage of water saturation, an average of 38%. There is no sign of GWC in this sand as well. A4 was penetrated to a maximum depth of 9349 ft sub sea. Table 3 (end of paper) shows the detail of A4 from all fourteen wells.

New Wells

Newly drilled development wells (T 12, T 13 and T 14) descriptions are presented in Table 4(end of paper).

METHODOLOGY

Subsurface maps of A sand (A2, A3, and A4), B sand (B3) and C sand (C2 and C3) were constructed by IKM (1991). All maps were completed with insufficient data. In this study, subsurface maps of A sand (A2, A3 and A4) have been revised. To revise the maps, interpretive contouring method was used. In this method 3D and 2D pictures of the reservoir and position of the wells have been visualized to develop a realistic interpretation. The sequence of steps that were used in constructing the revised subsurface maps are: (1) data validation, (2) data interpretation, (3) data extraction, (4) mapping, and (5) review. A flow diagram of this methodology is shown in Fig. 1.

First step: *Data validation*

All seismic data were compared and corrected by BGFCL geologists.

Second step: *Data Interpretation*

All information (TVD, subsurface location, surface location etc) are explained categorically. This step was also done by BGFCL geologists.

Third step: *Data Extraction*

All information are transferred to the map so that it can be used effectively. Usually, transferring the data to a map is referred to as posting. At first, coordinates of new wells Titas 12, Titas 13, and Titas 14 are posted on the IKM subsurface map. Then true vertical depths (TVT) of all wells are posted on that map.

Fourth step: *Mapping*

A contour line is drawn through the reference TVD line (250 ft for A2 sand, 125 ft for A3 sand and 100 ft for A4 sand). Then all contour lines are shifted proportionately (50 ft for A2 sand, 25 ft for A3 sand and 25 ft for A4 sand). All subsurface geological maps are constructed in this step.

Last step: *Review*

In this step, the subsurface maps are fed as input data in a simulation study. In reservoir simulation, it was observed that simulation pressure curve matched with the history pressure curve. If this could not be achieved in the review stage, the whole process would have to be repeated from the first step for appropriate adjustments.
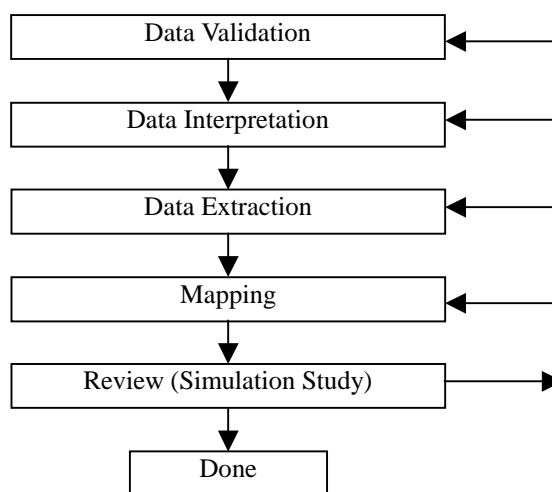

Fig. 1 Flow Diagram of the Methodology

SUBSURFACE MAPS

Any additional data from either drilling or additional seismic shooting will almost always change the subsurface mapping. Revised subsurface maps of A2, A3 and A4 sands are discussed and compared with IKM's maps separately.

A2 sand

A2 sand (Fig. 2 and 3) is the most continuous and thickest of all the major pay sands in Titas gas field. Fig. 2 is the original map of the A2 sand constructed by IKM. The reservoir rock volume of this map is $0.7E+11$ ft^3. The minimum thickness of A2 sand (Fig.-2) is 87 ft in T 1 and maximum thickness is 259 ft in T 6. According to IKM Geological, Geophysical and Petrophysical Report (1991), the maximum flank dip to the east is 12° and that to the west is 6°. The dip is much gentler in the north-south direction at $3^o\pm$. The closure has been found to extend much further to the north.

Fig. 3 is the revised subsurface map of the A2 sand and rock volume is $1.8E+11$ ft^3. The minimum thickness of A2 sand (Fig. 3) is 207 ft in T 10 and the maximum thickness is 259 ft in T 6 (Table 1). The average gross thickness around fourteen wells is 222 ft and net thickness is 127 ft. After drilling T 12, T 13 and T 14, it has been seen that the crest of the sand has extended to the north and to the east as well. In Fig. 3, the gross thickness is 256 ft in T 12, 213 ft in T 13 and 253 ft in T 14 respectively. On the other hand, in IKM's subsurface map (Fig. 2), the gross thickness were 100ft, 30 ft and 50 ft respectively at those locations. Considering all the new data, information and prediction, the subsurface map of the A2 sand was revised. However, no GWC has been encountered in any of the 14 wells todate. The zero edge of the reservoir has been interpreted (Fig. 3) based on the rate of thinning of the reservoir. This is the closest approximation that may be made on the basis of available data.
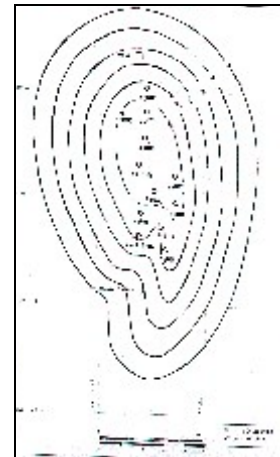

Fig. 2 Gross Thickness Map of A2 Sand

Fig. 3 Revised Gross Thickness Map of A2 Sand

A3 sand

According to IKM Geological Geophysical and Petrophysical Report (1991), the A3 sand (Fig. 4) is an analogue of the A2 sand both structurally and stratigraphically. It is separated from A2 sand by a continuous shale interval of variable thickness. The A3 sand generally mimics the A2 sand in its amplitude signature both in the dip sections and in the strike sections. It is thinner than the A2 sand. Fig. 4 is the subsurface map of the A3 sand and was constructed by IKM. The reservoir rock volume calculated by IKM was $0.4E+11$ ft^3.

The minimum gross thickness of A3 sand (Fig. 4) is 89 ft in T 5 and that of maximum is 128 ft in T 6. The average gross thickness is 113 ft around the fourteen wells. Fig. 4, that was constructed from old data, presents the gross thickness of 60 ft in T 12, 25 ft in T 13 and 25 ft in T 14 respectively. This is not correct. Actual thickness is 92 ft in T 12, 95 ft in T 13 and 118 ft in T 14 (Table 2). For this reason, IKM subsurface map was revised using all the latest data. Fig. 5 is the revised subsurface map of A3 sand and new rock volume is $0.92E+11$ ft^3. No GWC was observed in the fourteen wells drilled to date. The zero edge of the pool has been defined in Fig. 5 on the basis of available data.

A4 sand

Fig. 6, that was constructed by IKM shows the gross thickness contour of A4. All the locations of the new wells are shown as zero thickness in this map. Data from the newer wells presents a dramatic change from this screen.

Fig. 7 is the revised subsurface map of A4 sand. Actual gross thick are 79 ft in T 12, 92 ft in T 13 and 82 ft in T 14 respectively. Rock volume of IKM subsurface map was $0.2E+11$ ft^3. But the new map has the rock volume of $0.4E+11$ ft^3. Based on the rate of thinning of the reservoir from well control, the zero edge of the

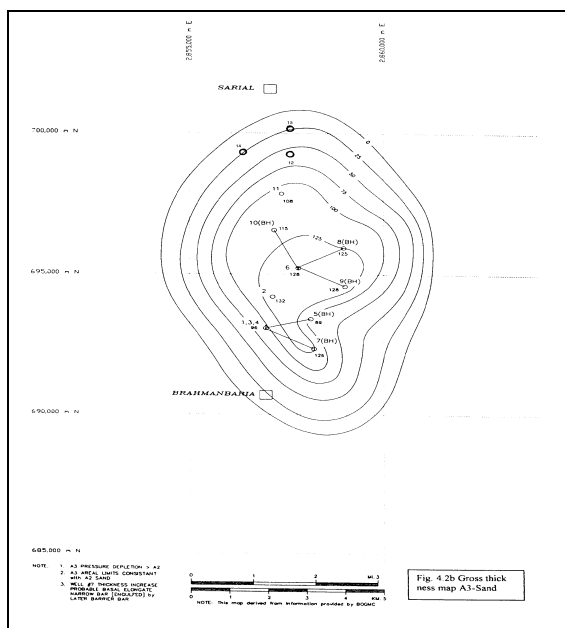reservoir has been explicated (Fig. 7). It is a good approach that may be made on the basis of available data.
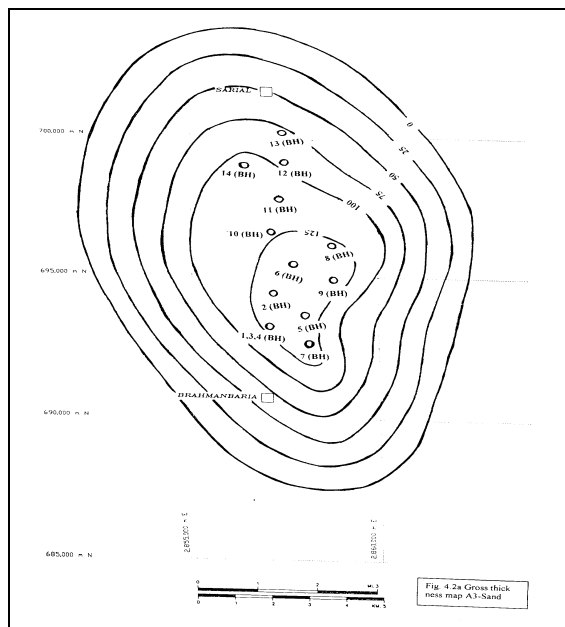

Figure 4 Gross Thickness Map of A3 Sand

Figure 5 Revised Gross Thickness of Map of A3 Sand
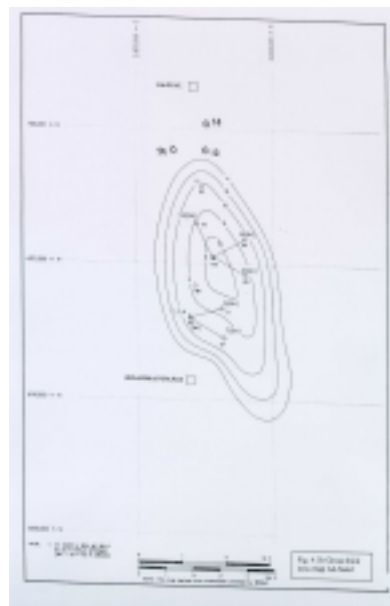
Figure 6 Gross Thickness Map of A4 Sand
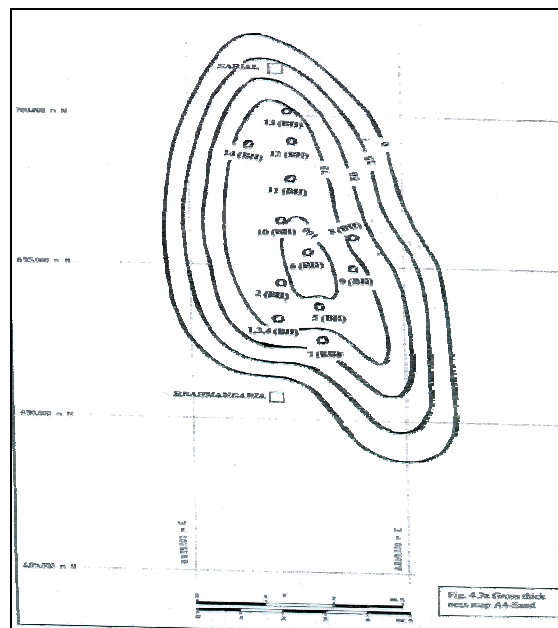
Figure 7 Revised Gross Thickness Map of A4 Sand

VOLUMETRIC RESERVE OF A-SAND

Volumetric method determines the initial reservoir volume of hydrocarbon accumulation, geological and geophysical evidence of pool size and shape. Logs estimates the reservoir porosity and water saturation. The accuracy of these volumetric estimates depends on the quality of seismic and log data but is severely affected by well density. In calculating gas initial in place (GIP), revised subsurface maps were used where all the latest well data were used to prepare the maps. Sand wise GIP and related parameters are shown in Table 5(end of paper). GIP estimation by IKM is presented in Table 6(end of paper)

VALIDATION

Initial gas in place of Titas gas field is 4.132 TCF (Petrobangla, December 1998) and recoverable reserve is 2.10 TCF. The initial reservoir pressure of the sands A, B and C were 3991.2 psia, 4225.7 psia and 4404.6 psia respectively. Until January 31, 2000 the cumulative gas production from A sand was 1.368 TCF. Sands B and C together have produced 0.308 TCF of gas during the same period. In January 1, 1999 the average reservoir pressure of A sand was 3286 psia and that of the sands B and C was 3174 psia. It has shown that there is no aquifer support in the sand A (Haq, M.B. 2001). These pressure and production data clearly indicate that the initial volumetric estimate of the Titas gas field is incorrect.

The accuracy of the newly constructed maps were validated with the help of material balance calculation and simulation study (Haq, M.B. 2001). Reservoir simulation was conducted using the maps. In simulation study, the history pressure was matched with the simulated pressure. The GIP of A sand found by history matching was 9.13 TCF. This is very close to the GIP value of 9.08 TCF found from the volumetric estimate.

Material balance study, both flowing and classical, was conducted to compare the GIP values of volumetric reserve(Haq, M.B. 2001). The GIP value of A sand based on the classical material balance was found to be 9.241 TCF and from flowing material balance technique was 9.239 TCF. Both the values are close match of the value from the newly constructed subsurface maps.

CONCLUSIONS

1. The volumetric GIP was 3.16 TCF (proved 2.13 TCF and probable 1.03 TCF) estimated by IKM. The present study finds the value as 9.08 TCF that is nearly three times greater. The additional reserve (5.92 TCF) as found by this study has a great economic impact as well as a significant influence on national energy planning.

2. No gas water contact has been identified in the A sand.
3. The results of the newly constructed maps were validated properly and seem to approach the true reserve of the field.

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Table 1 'A2' Pay Sand (All Depths in TVD)
(ONGC, 2000)

Well Name	KB (ft ss)	Top (ft ss)	Base (ft ss)	Gross Thickness (ft)	Net Thickness (ft)
T 1	40	8593	8803	210	89
T 2	39	8524	8737	213	66
T 3	40	8583	8800	217	72
T 4	40	8626	8849	223	66
T 5	41	8508	8688	180	148
T 6	29	8498	8757	259	102
T 7	42	8573	8783	210	92
T 8	40	8586	8803	217	148
T 9	40	8593	8809	217	148
T 10	40	8498	8727	230	157
T 11	57	8642	8849	207	157
T 12	54	8708	8964	256	174
T 13	54	8865	9079	213	171
T 14	54	8701	8954	253	184

Table 2 'A3' Pay Sand (All Depths in TVD) (ONGC, 2000)

Well Name	KB (ft Ss)	Top (ft Ss)	Base (ft Ss)	Gross Thickness (ft)	Net Thickness (ft)
T 1	40	8829	8960	131	108
T 2	39	8773	8911	138	105
T 3	40	8829	8964	135	95
T 4	40	8878	9010	131	82
T 5	41	8727	8859	131	105
T 6	29	8773	8855	82	62
T 7	42	8832	8960	128	92
T 8	40	8846	8970	125	89
T 9	40	8849	8954	105	92
T 10	40	8757	8878	121	89
T 11	57	8885	9000	115	66
T 12	54	9010	9101	92	46
T 13	54	9128	9223	95	52
T 14	54	9003	9121	118	89

Table 3 'A4' Pay Sand (All Depths in TVD) (ONGC, 2000)

Well Name	KB (ft Ss)	Top (ft Ss)	Base (ft Ss)	Gross Thickness (ft)	Net Thickness (ft)
T 1	40	9006	9101	95	89
T 2	39	8947	9026	79	75
T 3	40	9003	9105	102	79
T 4	40	9049	9151	102	66
T 5	41	8921	9003	82	62
T 6	29	8908	9026	118	52
T 7	42	9049	9111	62	26
T 8	40	9033	9092	59	43
T 9	40	9016	9095	79	49
T 10	40	8924	8993	69	52
T 11	57	9046	9131	85	43
T 12	54	9144	9223	79	59
T 13	54	9252	9344	92	69
T 14	54	9161	9243	82	72

Table 4 Properties of the New Wells (ONGC, 2000)

	Titas 12	Titas 13	Titas 14
Subsurface Location	N698903m E2857000m	N698979m, E2856918m	N699140m, E2856295m
Elevation (ft)	GL: 24 MSL KB:54 MSL	GL: 24 MSL KB:54 MSL	GL: 24 MSL KB:54 MSL
Well Type	Inclined, S-type	Inclined, S-type	Inclined, S-type
Drilled Depth (MD)	9863 (ft) KB	10493 (ft) KB	10992 (ft) KB
Date of Completion	August 22, 1999	December 03, 1999	March 3, 2000
Drilling Contractor	ONGC, India.	ONGC, India.	ONGC, India.
Av. Poro. (A sand)	20%	20%	20%
Av.Perm. (A sand)	280mD	280mD	280mD

Table 5 Sand Wise GIP of A-sand

Sand	Layer	hn/hg	H net(ft)	Area (sq.ft)	ϕ	(1-Swi)	Bgi(ft3/scf)	GIP (scf)
Sand-A2	1	0.75	37.5	3E+08	0.2	0.64	0.0044	4E+11
Sand-A2	2	0.75	37.5	6E+08	0.2	0.64	0.0044	6E+11
Sand-A2	3	0.75	37.5	9E+08	0.2	0.64	0.0044	1E+12
Sand-A2	4	0.75	37.5	1E+09	0.2	0.64	0.0044	1E+12
Sand-A2	5	0.75	37.5	2E+09	0.2	0.64	0.0044	2E+12
Sand-A3	6	0.75	18.8	4E+08	0.2	0.67	0.0044	2E+11
Sand-A3	7	0.75	18.8	6E+08	0.2	0.67	0.0044	4E+11
Sand-A3	8	0.75	18.8	9E+08	0.2	0.67	0.0044	5E+11
Sand-A3	9	0.75	18.8	1E+09	0.2	0.67	0.0044	7E+11
Sand-A3	10	0.75	18.8	2E+09	0.2	0.67	0.0044	1E+12
Sand-A4	11	0.8	20	2E+08	0.2	0.62	0.0044	1E+11
Sand-A4	12	0.8	20	4E+08	0.2	0.62	0.0044	2E+11
Sand-A4	13	0.8	20	6E+08	0.2	0.62	0.0044	3E+11
Sand-A4	14	0.8	20	8E+08	0.2	0.62	0.0044	5E+11
						Total GIP =		9E+12

Table 6 Sand Wise GIP of A-sand (IKM, 1991)

Sand	Rock Volume (acre-ft)	Hn/Hg	ϕ	Swi	Bgi(ft3/scf)	GIP (BCF) Proved	GIP (BCF) Probable
Sand-A2	1579100	0.571	0.198	0.36	0.004364	1140.5	880.0
Sand-A3	935095	0.68	0.192	0.32	0.004374	826.8	52.4
Sand-A4	391925	0.384	0.191	0.39	0.004392	165.2	97.8
Sub Total						2132.5	1030.2
Total						3162.7	