Ali Sharif
Senior Petroleum Engineer
Resources Branch

Tight gas resources in Western Australia

This article stems from a study by the Petroleum and Royalties Division's Resources Branch on tight gas in March 2007. There are a number of significant tight sandstone reservoirs onshore and offshore in Western Australia that could contain gas resources of as much as 198 Gm^3 (7 Tcf). This article only describes Western Australia's onshore structures, Whicher Range, Gingin and Warro. The key to producing this vast resource is locating areas and drilling wells where natural fractures abound. Where natural fractures are scarce, hydraulic fracturing may be used to give the gas an easier pathway to the well. Proper applications of existing and new technologies in tight-gas wells can double the amount of gas produced during the first year.

INTRODUCTION

Tight gas refers to natural gas produced from reservoirs that have very low porosities and permeabilities. Reservoirs are usually sandstones, although carbonate rocks can also be tight-gas producers. The standard industry definition for a tight-gas reservoir is a rock with matrix porosities of 10% or less and permeabilities of 0.1 millidarcy (mD) or less, exclusive of fracture permeability. Many "ultra-tight" gas reservoirs have in situ permeabilities as low as 0.001 mD.

In the US, tight sandstone production has played an important role in past gas production and will play a crucial role in the future. Production was projected to increase steadily through the year 2000 and then escalate dramatically. By the year 2010, production is conservatively projected to increase to 105 Gm^3 per year (3.7 Tcf/year), almost doubling current levels and increasing fourfold from 1970.

In the Cooper Basin, which is Australia's most prolific onshore petroleum province, tight gas resources were only recognised and given focus in recent years after the more conventional gas resources began to decline sharply.

Hydraulic fracturing is the key technology in tight gas development. Most tight reservoirs have to be fractured before they will flow gas at commercial rates. In the 1980s, thick, cross-linked polymer fluids that carried tremendous volumes of sand were popular for fracturing tight-sand reservoirs, but the high cost of these treatments rendered many plays uneconomic. In the 1990s, slick-water fracturing techniques were developed that used high volumes of water and low concentrations of proppant. These jobs were much less expensive and opened some new areas to commercial development.

The key to producing this vast resource is locating areas and drilling wells where natural fractures abound. If natural fractures are scarce, hydraulic fracturing is used to give the gas an easier pathway to the well. Proper applications of existing and new technologies in tight-gas wells can double the amount of gas produced during the first year. The bad news is that there are still significant technical challenges that operators and service companies must overcome to maximise production from tight-gas fields.

Some of the technical issues that need to be addressed include:

- better reservoir evaluation;
- better completion, perforating and well-testing methods;
- multistage fracturing;
- proppant flowback, re-stimulation; and
- formation collapse and casing failure.

Identifying the best locations for tight-gas well completions requires a host of reservoir evaluation technologies, including seismic interpretation, logging and well testing. In many cases the tight-gas reserves are in deep zones or bypassed zones of the existing wells.

One of the principal technologies for identifying bypassed reserves in existing fields is reservoir simulation, which can highlight missed pockets of gas so operators can plan a proper infill drilling program. However, identifying the location of the gas reserves is not the only key to success. Operators must assess how much gas will actually be produced. Conventional logs or core analysis methods do not measure the adsorbed gas component of tight gas shale.

WHICHER RANGE FIELD

The Whicher Range gasfield is located onshore, approximately 200 kilometres south of the city of Perth, Western Australia and 22 kilometres south of the city of Busselton (Figure 1). The Whicher Range field was discovered in 1968 when the Whicher Range 1 well was drilled near the centre of a large anticline, some 12 kilometres by 6 kilometres, and discovered gas in a 450 metre interval of Permian sandstones. Interpretation of the wireline logs indicates an average porosity of 9% and an average water saturation of approximately 55% in the gas column. The original gas in-place for the Whicher Range gas accumulation is 46 Gm^3 (1.64 Tcf).

Whicher Range 1

Whicher Range 1 was drilled in 1968. The best test zone flowed gas at 53.8 km^3/d (1.9 MMcf/d) and the aggregate of all zones, 141.5 km^3/d (5 MMcf/d). The operator, Union Oil, concluded that the reservoir was mostly of low permeability and attempted to improve gas flow with water based fracture stimulation.

Whicher Range 1 was plugged and abandoned after a failed reservoir stimulation attempt. The well was re-entered by Pennzoil Exploration Australia in November 1997. The objective of re-entry was to fracture stimulate the gas bearing reservoirs. The results are discussed further on.

Whicher Range 2

In 1980, Mesa Australia Limited drilled Whicher Range 2 well, one kilometre southeast of Whicher Range 1 in the expectation that modern drilling fluids would allow the reservoir to flow gas at commercial rates without fracture stimulation. Like Whicher Range 1, Whicher Range 2 had good gas shows during drilling in Permian sandstones. Casing was set and a number of production and drill stem tests were carried out through perforations. Several tests flowed gas to surface but at rates much less than those from Whicher Range 1.

Mesa concluded that porosities and permeabilities in Whicher Range 2 were lower than those recorded from Whicher Range 1 and the well was plugged and abandoned. The Whicher Range 2 well penetrated three thick near-vertical Cretaceous age dolerite dykes, immediately above the Permian reservoir. Intrusion of these dykes is likely to have had a detrimental affect on nearby reservoir quality and may be an explanation for the anomalous results. No dolerite has been intersected in any other Whicher Range well.

Whicher Range 3

In 1982, BP Petroleum Development Australia Pty Ltd drilled Whicher Range 3 well, 3.5 kilometres south of Whicher Range 2, with the objective of obtaining commercial gas flow rates by applying hydraulic fracture stimulation. This well was located on the southern flank of the large Whicher Range dome, so that the Permian reservoir was intersected 147 metres down dip of Whicher Range 2. Despite the down-dip location, significant gas shows were encountered while drilling. After the failures of Whicher Range 2 and 3, work on the area ceased and eventually the permit was relinquished.

In late 1996, Southern Amity Inc. and its Joint Venture participants bid for and won in open competition Exploration Permit EP 408, which included the Whicher Range field.

Whicher Range 4

Pennzoil Exploration Australia Inc. farmed into the permit with the objective of bringing the Sue Group reservoirs to production using modern hydraulic fracture stimulation techniques. Pennzoil, as the operator, drilled and fracture stimulated the Whicher Range 4 well and re-entered and fracture stimulated the Whicher Range 1 well between October 1997 and June 1998.

After the Pennzoil campaign, extensive core studies by Stim-Lab Inc. established that the Sue Group sandstone reservoir permeability is adversely affected by water-based drilling and stimulation fluids.

A classical “water-block” occurred due to a combination of pore geometry and clay swelling and trap stimulation fluid around the artificial fractures. Reservoir pressure was insufficient to overcome the water block and force water back to the well bore. The water block thus prevented much of the gas in the reservoir from reaching the wellbore. The studies concluded that water should not be used in stimulation and preferably not in drilling. Pennzoil mini-frac results showed evidence of natural fracture permeability, which was compromised by the use of cross-linked borate gels during stimulation.

The Stim-Lab Inc study also recommended a re-stimulation of Whicher Range 4 using liquid carbon dioxide to attempt to reduce the water block and increase gas flow. The re-stimulation, a first in Australia, was carried out by Southern Amity Inc. in late 1999 and successfully increased flow rate to a stabilised 78 km^3/d (2.77 MMcf/d) on a 9.5 mm (3/8 inch) choke. This was the first stimulation to increase flow rate at Whicher Range.

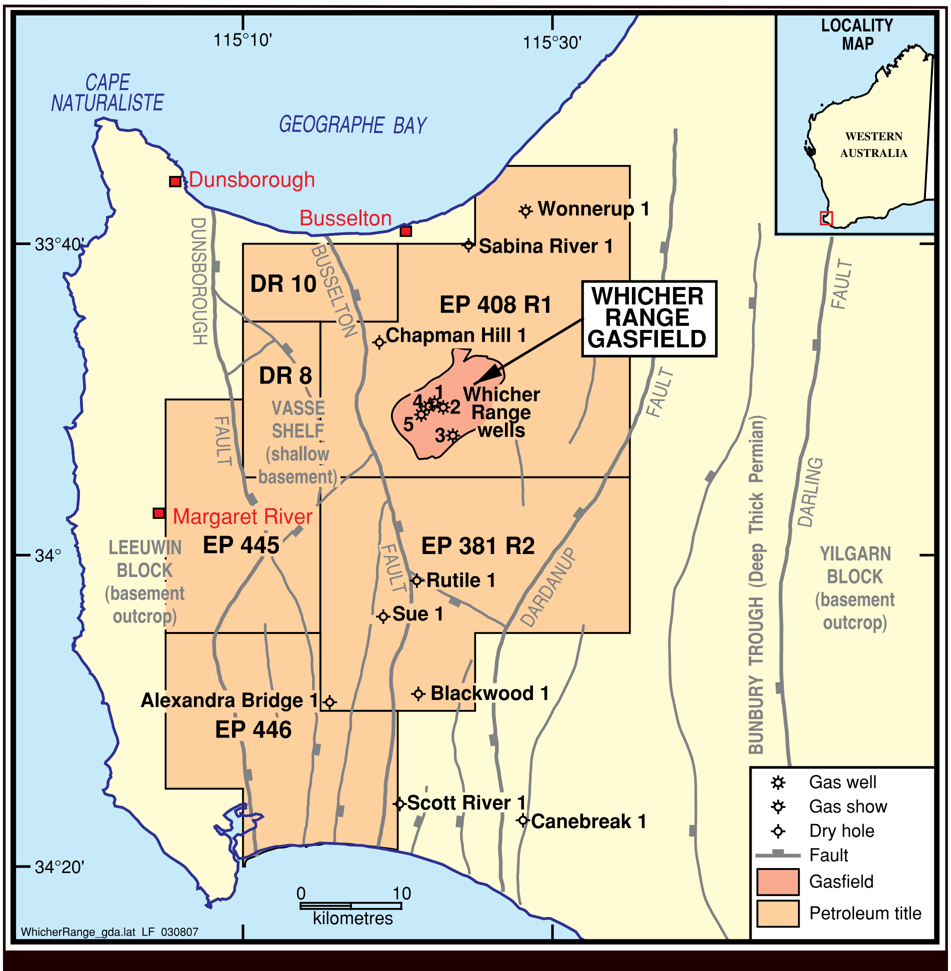

Figure 1. Location map of the Whicher Range gasfield.

Following fracture stimulation, the well was flowing from a combined test of two zones. The first zone, between 4380 and 4390 metres, was perforated, fracture simulated and flowed gas at a rate too small to measure. The second zone, between 4215 and 4224 metres, was perforated and the combined zones flowed to the on-site test separator. This test, over a three-hour period, resulted in a combined average flow rate of 39.6 km^3/d (1.4 MMcf/d).

Although encouraging, the flow rate was not considered to be commercially viable. Significant, however, was the well test planned following fracture stimulation of the 4215 to 4224 metre interval, which gave a clearer indication as to the potential commercial development of this gas resource.

Whicher Range 5

The fifth well on the Whicher Range structure, operated by Southern Amity Inc., was drilled to appraise the flow capacity of the gas-bearing Sue Group in the same fault compartment as Whicher Range 1 and 4.

To achieve commercial deliverability from Whicher Range 5, it was recommended to drill the reservoir section with air to minimise damage to both matrix and natural fracture permeability. Then, if sufficient gas flow was not obtained it was recommended to run casing and fracture stimulate the gas zones using oil and liquid carbon dioxide, to avoid water block in the matrix and preserve fracture permeability, thereby maximising gas flow. Hydrocarbon shows were encountered throughout the logged interval, 3676-4300 mMD, with porosities ranging from 15% down to around 2%. Water saturation in the best sands was in the order of 30%, and in the lower porosity sands increased to approximately 50%.

The Whicher Range 5 well was suspended as a potential gas producer in January 2004. A multi-zone fracture stimulation program on the Whicher Range began in July 2004. The planned fracturing program was to be conducted over five sandstone sequences, starting from the bottom zone and progressing, individually to the uppermost zone. Due to the previous recognised damage by water, a diesel based fluid was used for fracturing.

Air drilling at Whicher Range 5 was not successful due to the fact that the campaign did not help release the gas to the surface and borehole instability caused major problems. The air drilling confirmed that matrix porosity at Whicher Range is gas saturated, but this matrix has very low effective porosity and is unlikely to contribute at commercial rates to production in its own right.

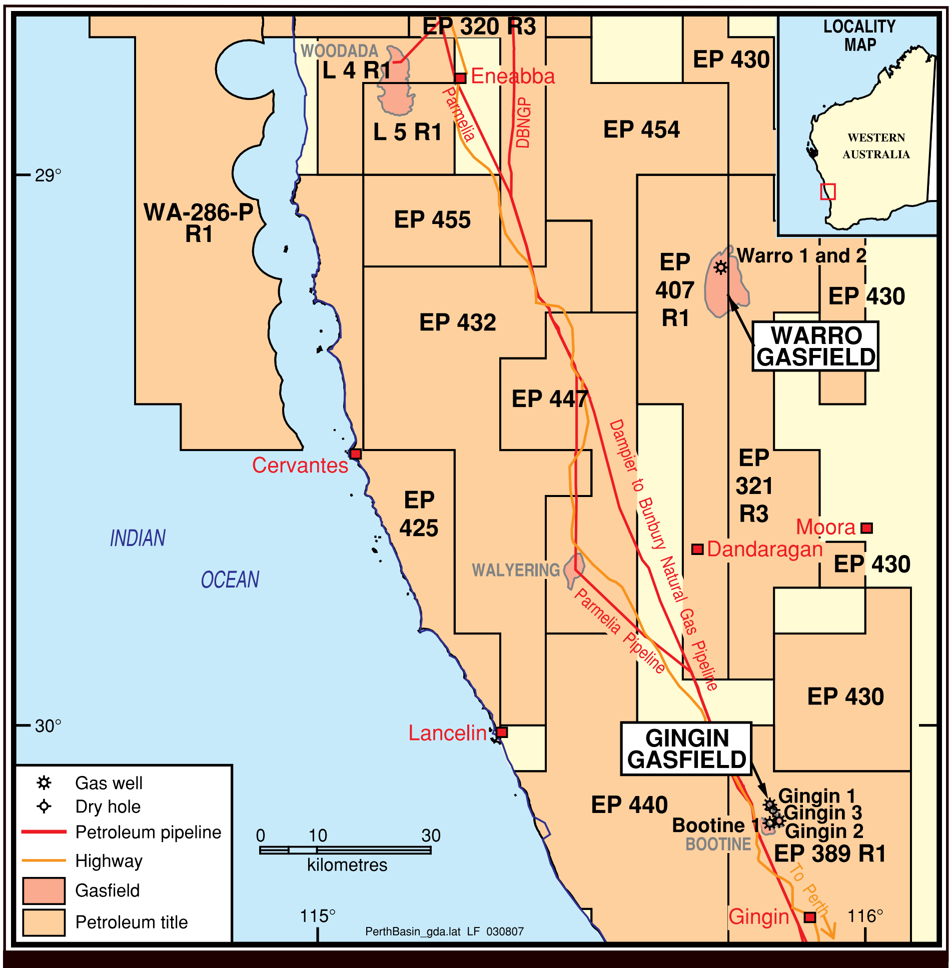

Figure 2. Location map showing the Gingin and Warro gasfields in the onshore Perth Basin.

Reservoir damage induced by water based mud did not appear to be the critical inhibitor to commercial flow rates. Low reservoir permeability was the major issue. Well location was also critical. The well was drilled on the southwest sector of the field in an area known to be affected by dolerite sills that have locally metamorphosed the reservoir to the extent that during the fracture program, at the maximum pump fracture pressure of 65 000 kPa, fracture could not be initiated.

The results of Whicher Range 5 demonstrated that any potential to commercially develop the large gas resource at the Whicher Range gasfield will be reliant on the presence of naturally occurring fractures within the Sue Group. The open fractures are typically developed as high angle extensional fractures and/or more importantly critically stressed high angle conjugate shear fractures. Their high angle makes it difficult to intersect such fractures in a vertical well bore. Whicher Range 5 was plugged and abandoned in January 2005.

Way Forward

Fracturing or horizontal drilling is still potentially applicable. Southern Amity Inc proposed a study by world recognised experts, Geomechanics International (GMI) to determine the type, extent and spatial orientation of fracture permeability at Whicher Range. If there is sufficient encouragement in the initial two phases of the study, a final phase to determine how best to orientate and engineer an underbalanced inclined or lateral well to optimise the intersection of open fracture permeability will be completed for consideration by the Joint Venture.

The study will involve constructing a geomechanical model of the Sue Group sandstones to determine the extent of fracture permeability at Whicher Range based on the availability of hard data, primarily from Whicher Range 4 and 5.

Subject to an encouraging outcome in the initial two phases of this study, well bore stability would be investigated to determine the optimum strategy for under balanced inclined/lateral drilling and the merits of hydraulic fracture stimulation to intersect maximum fracture development and hence productivity.

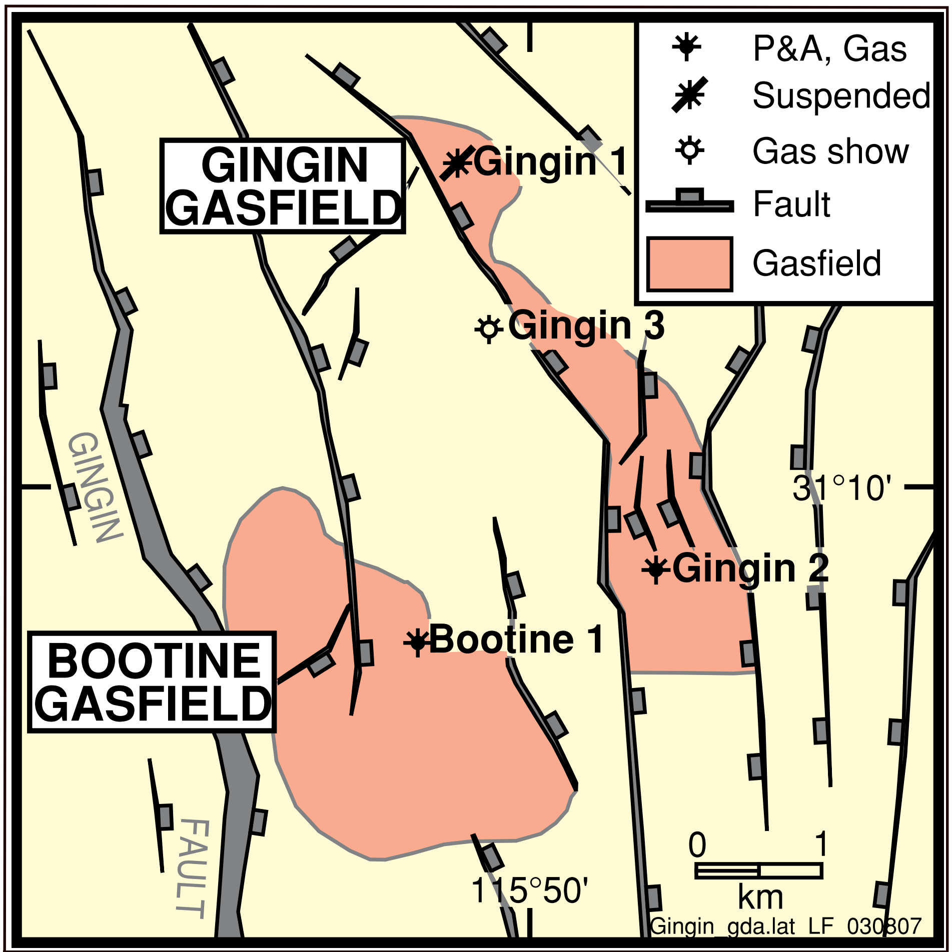

Figure 3. Gingin and Bootine gasfields mapped at the Lower Jurassic Cattamarra Coal Measures (after Empire Oil Company (WA) Ltd, 1999).

OTHER TIGHT GASFIELDS

Gingin Gasfield

The onshore Gingin field is in Exploration Permit EP-389 in the Perth Basin, 105 kilometres north of Perth (Figure 2). The field was discovered in 1965 by West Australia Petroleum Ltd (WAPET) with the drilling of Gingin 1, which intersected gas-saturated sandstones over a gross interval of approximately 300 m in the Lower Jurassic Cattamarra Coal Measures (Figure 3). Of a total of 19 drillstem tests, six tests in individual reservoir sandstones over the interval 3864.9-4154.4 mKB produced gas at rates between 63 and 109 km^3/d (2.25-3.85 MMcf/d). Three appraisal wells, Gingin 2, Bootine 1 and Gingin 3 were subsequently drilled.

Long-term production tests from Gingin 1 commenced in March 1972, however, production lasted only until December 1972. Additional gas was produced at a much-reduced rate from June 1975 until January 1976, when further production could not be sustained. Gas was piped south to Perth via the West Australian Natural Gas Pipeline. A cumulative total of 48 545 km^3 (1.71 Bcf) of gas and 3169 kL (19.9 Mbbl) of condensate were produced.

High density seismic survey is crucial to better define the Gingin structure. However, this is currently not possible due to environmental constraints. The resource potential in the greater Gingin area could be as much as 28 Gm^3 (1 Tcf) some of which could be conventional reservoirs.

Warro Gasfield

The Warro structure is a large unfaulted growth-type anticline on the east of the northern part of the Dandaragan Trough (Figure 2). The Warro Anticline is the largest of four recognised prospects in the “east flank play”. A review of static corrections integrating 1976 seismic data showed that a complex thick and variable weathering situation exists on the structure. The accuracy of resultant static corrections has had a considerable influence on the shape of the structure.

Two wells have been drilled in this field by WAPET in the late 1970s indicating a substantial gas column in the Warro structure (Warro 1 and Warro 2). Warro 1 was drilled to the northeast of the Walyering field and east of the Dongara-to-Perth gas pipeline. Warro 2 had been drilled to 4854 m and was the deepest well in Australia at the time.

One of the key factors for the lack of success in the Warro field was that the initial wells were drilled with rudimentary well engineering supervision. For instance both Warro wells were drilled with extremely high mud weights that caused significant formation damage. The wells did not flow at commercial rates.

An attempt to enter Warro 2 by AusAm Resources in January 2002 failed due to casing integrity. Since then the permit holders have not carried out any significant work to delineate the field. The resource potential of the Warro structure is considered to be approximately 141 Gm^3 (5 Tcf) some of which may not be tight gas. This potential reserve if developed could sustain the future electrical requirements for the south west region of Western Australia.

CONCLUSIONS AND RECOMMENDATIONS

Onshore tight gas in Western Australia would only be competitive close to recognised markets or existing pipelines.

As such, a follow-up study of tight gas has been proposed by DoIR, in which the potential areas of the State would be targeted in the Perth, Bonaparte and Canning Basins. Such a study would encompass existing discovered tight gas resources yet to be developed and potential areas yet to be explored. The study will focus on the following deliverables:

- Inventory of existing tight gas prospects and resource sizes known in the State;
- Evaluate why existing tight gas prospects have not yet been developed;
- Determine what would be required to bring these tight gas resources to market;
- Determine those onshore areas of the State with potential for tight gas; and
- Determine a strategy for increasing industry’s focus on exploration and exploitation of tight gas areas.