# What we know, what we don’t know, and things we do not know we don't know about hydraulic fracturing in high stress environments

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## SUMMARY

Hydraulic fracturing in many Australian Basins, particularly the Cooper Basin has been successful in higher permeability, structured conventional plays. However, adaptation of North American strategies to Australia’s complex, and highly stressed unconventional areas has resulted in less than adequate performance to progress further investment into widespread development these resources. This presentation will explore the obvious differences between Australian and North American stress settings, and the problems manifested by those differences in hydraulic fracture containment and behaviour. Further, as more unconventional targets are attempted, complementary strategies need to be considered based on fundamental geomechanical principles, relative to these basinal environments.

This presentation will explore several problems, emerging potential solutions, and areas of ongoing research with the purpose of aiding Australia to tap into a vast supply of potential unconventional resources, which are currently under-appraised.

**Key words:** Hydraulic fracturing, Cooper Basin,

## INTRODUCTION

Several Australian Basins are being pursued as unconventional reservoir systems (e.g., a tight gas, shale gas, basin-centred gas) since the early-2000s. New activities in the Cooper Basin have been driven by Santos’ forced relinquishment of the Nappamerri Trough in 1999 (Menpes, 2012) and further definition of the Roseneath, Epsilon, and Murteree (REM) sequences. Whilst outside the Cooper Basin further shale gas appraisal work has been done in the McArthur Basin, Betaloo Sub Basin and the Lawn Hill Platform. Based on the highly fluvial and lacustrine geology and differential stress loadings based on structuring, a significant amount of research has been placed on defining the structure to high grade areas for unconventional reservoir targets(Lang, S.C. & Jochen, 2000; Lang, S.C. et al., 2000; Lang, S.C. et al., 2001).

In the late-1990s, attempts were made by Santos in the Nappamerri trough to develop an extractive technology for these deep unconventional reservoirs using conventional 2D and 3D seismic and hydraulic fracturing from vertical wellbores with little to no success. Their extensive R&D efforts and their collaborative research efforts with supplier applied research groups have been recognised by worldwide conference submissions, presentations and journal publications. Their failure to develop an extractive technology is the result of the unique geologic and stress conditions existing in the Cooper Basin that are rarely observed in North American settings (Johnson, R. L., Jr. & Greenstreet, 2003; Johnson, R. L., Jr. et al., 2000).

Santos in collaboration with researchers have published the most studies on the Cooper Basin and varying techniques to improve productivity (Beatty et al., 2007; Camac et al., 2012; Gilbert et al., 2005; Johnson, R. L., Jr. et al., 2002; Johnson, R. L., Jr. & Greenstreet, 2003; McGowen et al., 2007; Nelson, Chipperfield, Hillis, Gilbert & McGowen, 2007; Nelson, Chipperfield, Hillis, Gilbert, McGowen, et al., 2007; Pokalai et al., 2016; Roberts et al., 2001; Uribe et al., 2007). Recently, Beach, Senex and Real have performed additional hydraulic fracturing trials, with varying diagnostics, to develop a successful stimulation strategy for tight gas and shale gas resources using vertical wells and multistage hydraulic fracturing (Johnson, R.L. Jr. et al., 2016; Pitkin et al., 2013; Scott et al., 2013).

The need to research and develop a successful extractive technology for shale gas is a key element recommended by the Chief Scientist as part of Report by the Australian Council of Learned Academies for PMSEIC, June 2013. He noted that “substantial new research and exploration is required to turn that resource estimate into economic reserves, but following that there are no major technology gaps that will unduly hinder natural gas production from deep shale. Facilitating the necessary research and exploration provides opportunities to both the oil and gas industry and Australia more broadly, because the required focus is on understanding the dynamics of prospective sedimentary basins in their entirety (geology, hydrology, ecology).”

So, what do we know, what we don’t know, and things we do not know we don't know about hydraulic fracturing in high stress environments in Australian unconventional reservoirs.

## DISCUSSION

There are several problematic areas with respect to hydraulic fracturing in the Cooper Basin with some exacerbated by high operating temperatures. These are high overall stress levels, high near wellbore pressure loss, and pressure dependent leakoff. Generally, in a normal stress regime (i.e., North America) sandstones will have less horizontal stress loading than coals based on vertical stress loading. This is a function of their lower Poisson's ratio, or the property that describes the transference of vertical to horizontal stresses. However, in Australia and other areas of higher tectonic strains, the more brittle sandstones take on more tectonic stress than the more elastic coals. This can cause the sandstones to be of equal or higher stress to the coals. This effect of reservoir material properties causes the minimum and maximum horizontal stress values to vary layer-by-layer. Further as noted by studies of the Bowen Basin and Cooper Basin, the sandstones and shales can exist in a strike-slip regime whilst the coals exhibit near normal stress conditions (Johnson, R.. L. Jr. et al., 2015; Tavener et al., 2017). What we know is this causes difficulty with respect to fracture containment and fracture growth, whereby hydraulic fracture treatments growing into coals may not exhibit further height growth. What we don't know exactly is how to predict when and at what pressure threshold does a propagating fracture overcome stress and strong interfaces between materials and enter the coal.

The next problematic area associated with hydraulic fracturing in many areas of Australia are high near wellbore pressure loss (NWBPL) associated with fracture tortuosity. Fracture initiations may not be entirely Mode 1 fracture emanations as experienced in a low magnitude strike-slip or normal stress regimes. In the presence of high stresses, proximity of the minimum horizontal and vertical stresses, and the presence of natural fracturing, shear fracturing and natural fracture dilation can occur, resulting in high initiation pressures and fracture disorientation (Johnson, R.. L. Jr. et al., 2015; Nelson, Chipperfield, Hillis, Gilbert, McGowen, et al., 2007). As the fracture reorients, this region exhibits pressure drops indicative of the degree of disorientation, fluid viscosity and injection rates (Jeffrey & Zhang, 2010). We know this is occurring based on treatment diagnostics and several authors have proposed various methods to reduce or minimise these effects on treatment effectiveness. However, what we don't know is how far does this effect extend beyond the wellbore and affect the far field fracture propagation.

For example, Pitkin, et al., and Scott et al., recently noted the problematic nature of hydraulic fracturing from vertical wells in the deep Cooper Basin using highly instrumented fracture experiments in both shale (Figure 1 and 2) and tight gas (Figure 3 and 4) reservoirs. Figure 1 illustrates the direction of Holdfast 1, Stage 1 running NW-SE contrary to the E-W expected direction with evidences of a horizontal component. Figure 2 shows the predominantly horizontal fracturing in Encounter 1, Stage 2. Figure 3 and Figure 4 show 32 to 55% horizontal fracture components in tiltmeter data from Skipton 1, a multi-stage Patchawarra hydraulic fracture experiment. Thus, in a predominantly strike-slip environment with well documented E-W maximum horizontal stress azimuth, fracture azimuth appears to vary significantly away from the wellbore. This means the near wellbore effects may extend much further than we expect, and the pressure loss and high overall stresses may be the result of disoriented mixed-mode propagating hydraulic fractures. Despite efforts to reduce NWBPL by both authors, they were unable to significantly reduce its effects or alter fracture azimuths.

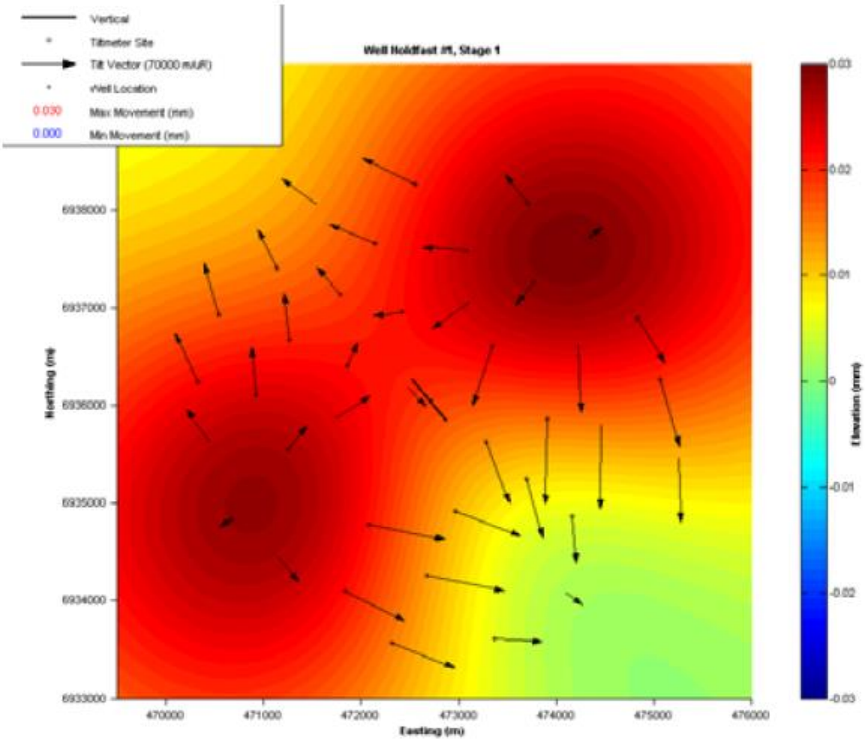



**Figure 1: Surface deformation tiltmeter representations of fractures in shale gas hydraulic fracturing experiments in Holdfast 1 well, Cooper Basin (Pitkin et al., 2012)**

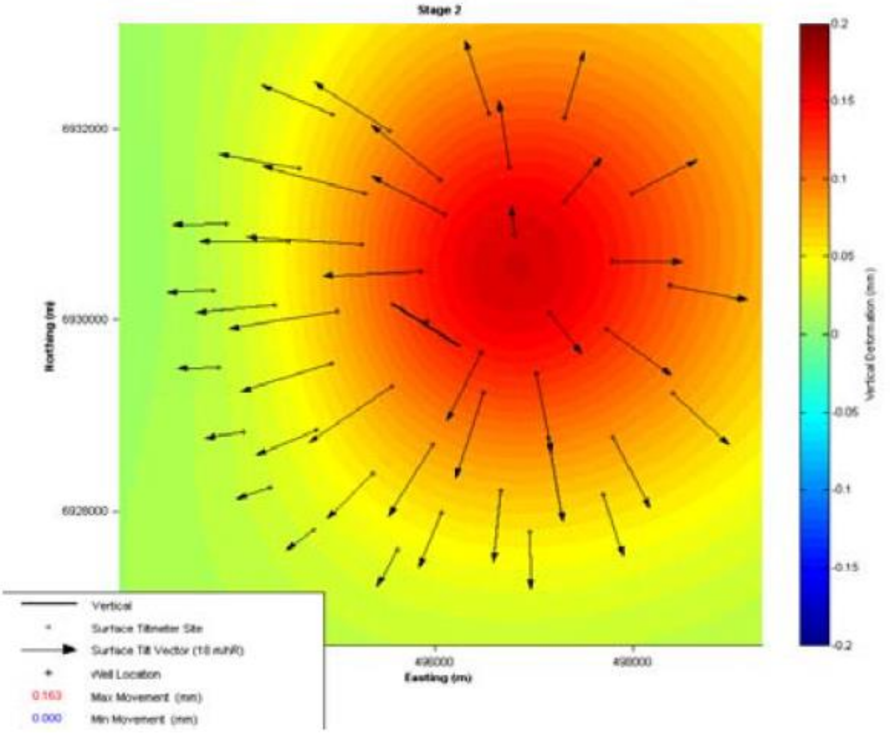



**Figure 2: Surface deformation tiltmeter representations of fractures in shale gas hydraulic fracturing experiments in Encounter-1 well, Cooper Basin (Pitkin et al., 2012)**

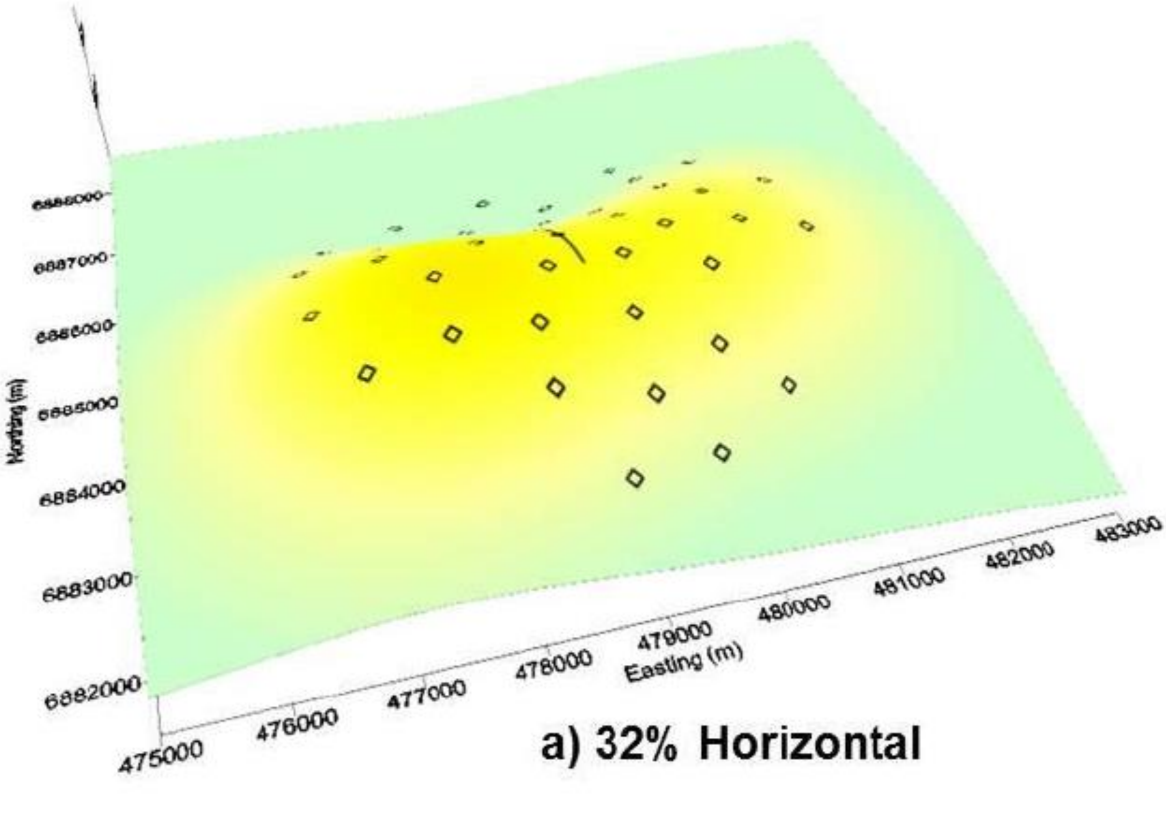



**Figure 3: Surface deformation tiltmeter representations of fractures in in tight gas hydraulic fracturing experiments in Stage 4, Skipton 1 well, Cooper Basin (Scott, M. P. et al., 2013)**

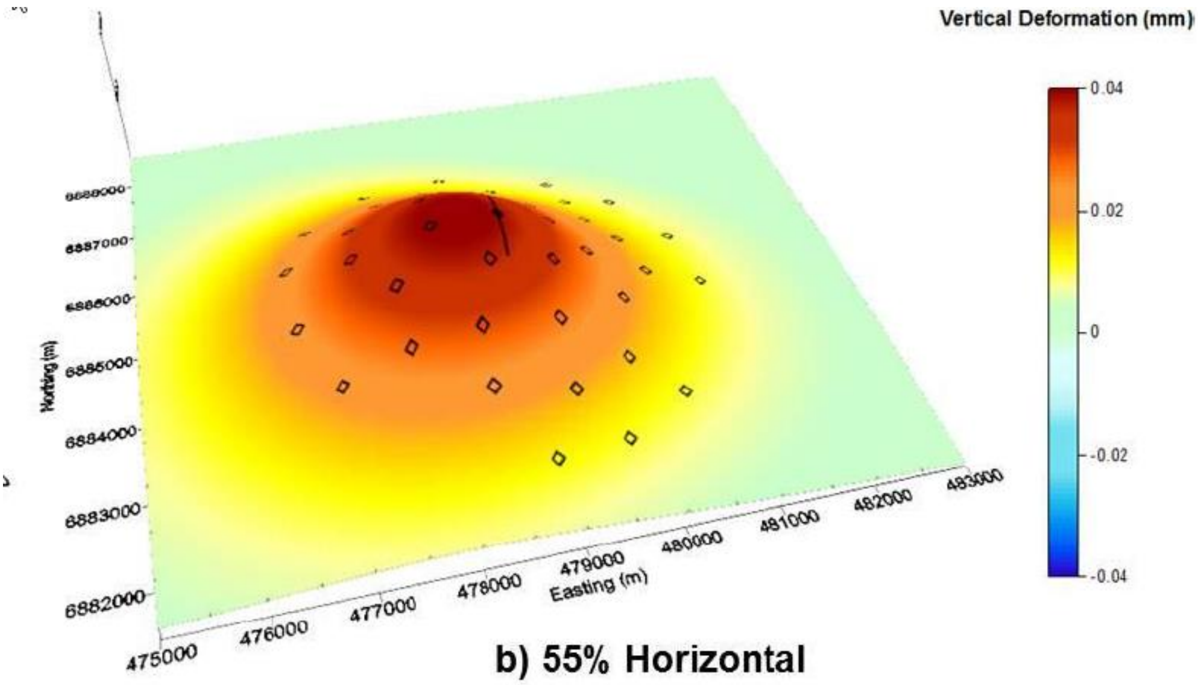
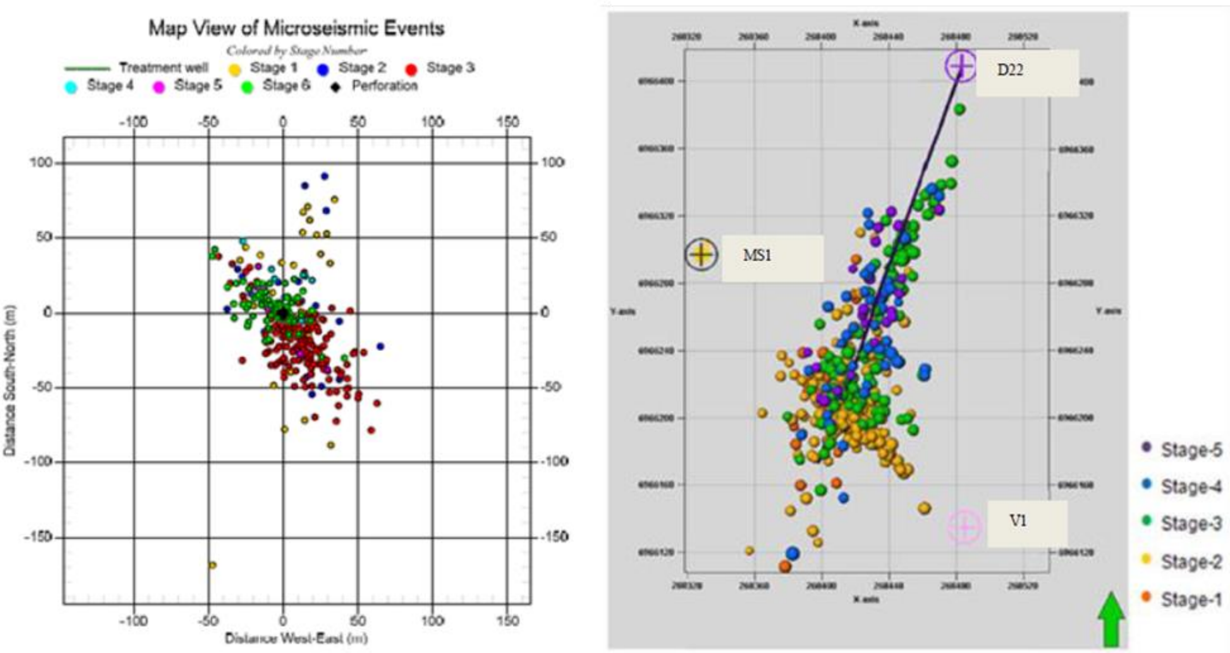



**Figure 4: Surface deformation tiltmeter representations of fractures in in tight gas hydraulic fracturing experiments in Stage 7, Skipton 1 well, Cooper Basin (Scott, M. P. et al., 2013)**

What we don't know for certain yet is whether fracture complexity can be reduced by orienting wells in the maximum horizontal stress direction and potentially inclining them to achieve more standoff between coals and sands in the fracturing sequence. When fracture complexity was noted in wells of similar ratios of deviatory horizontal stress magnitudes ($\delta\sigma_{HMax}/\delta\sigma_{hmin}$) in the Surat Basin, an experiment was done to incline wells at 27.5° and 60° from being vertical in the $\sigma_{HMa}$ direction. These efforts reduced the fracture complexity, relative to offset fracture experiments with similar diagnostics (Figure 5), and improved overall treatment results (Bentley et al., 2013; Johnson, R. L., Jr., Glassborow, et al., 2010; Johnson, R. L., Jr., Scott, et al., 2010). What is unknown is whether this may reduce near wellbore tortuosity and fracture complexity in an overall higher magnitude stress environment– the Cooper Basin.




(a) (b)

**Figure 5: Map view of microseismic events around a fracture interacting with natural fractures with (a) vertical wellbore in 2009 and (b) 27° and 60° wellbores inclined in $\sigma_{HMax}$ direction (after Bentley. et al., 2013)**

The final problematic area is pressure dependent leakoff (PDL), which causes premature screen outs and may contribute to lower fracture conductivity. A complex fracture propagating in a naturally fractured reservoir can create additional fracture complexity and even damage the primary fracture system, reducing fracture effectiveness based on the extent of fracture porosity or the overall net pressures experienced during the frac treatment (Johnson, R. L., Jr. et al., 1998). The shift to lower viscosity cleaner fluids in shale gas treatments was not only more economic, but less damaging to the natural fracture system and increase the stimulated reservoir volume (SRV). In the Barnett Shale a push to reduce crosslinked gel treatments over slick water treatments was precipitated by the observation that a majority of the frac treatment was pumped at net pressures far exceeding the fissure opening pressure, causing natural fracture damage, and correlating with reduced productivity (Johnson, R. L., Jr. et al., 2003).

We know how to modify frac treatments to reduce PDL effects, but what we don't know is what effect that reducing PDL may have on limiting the overall SRV of the treatment. Possibly embracing this additional fracture area and propping with clean fluids and graded particles might prop these pressure dependent fissures resulting in higher productivity as was been demonstrated by studies in coals using graded particle treatment fluids akin to Figure 5 (Keshavarz, Badalyan, Carageorgos, et al., 2015; Keshavarz et al., 2014; Keshavarz, Badalyan, et al., 2016; Keshavarz, Badalyan, et al., 2015a; Keshavarz, Badalyan, et al., 2015b; Keshavarz, Johnson, et al., 2016; Khanna et al., 2013).

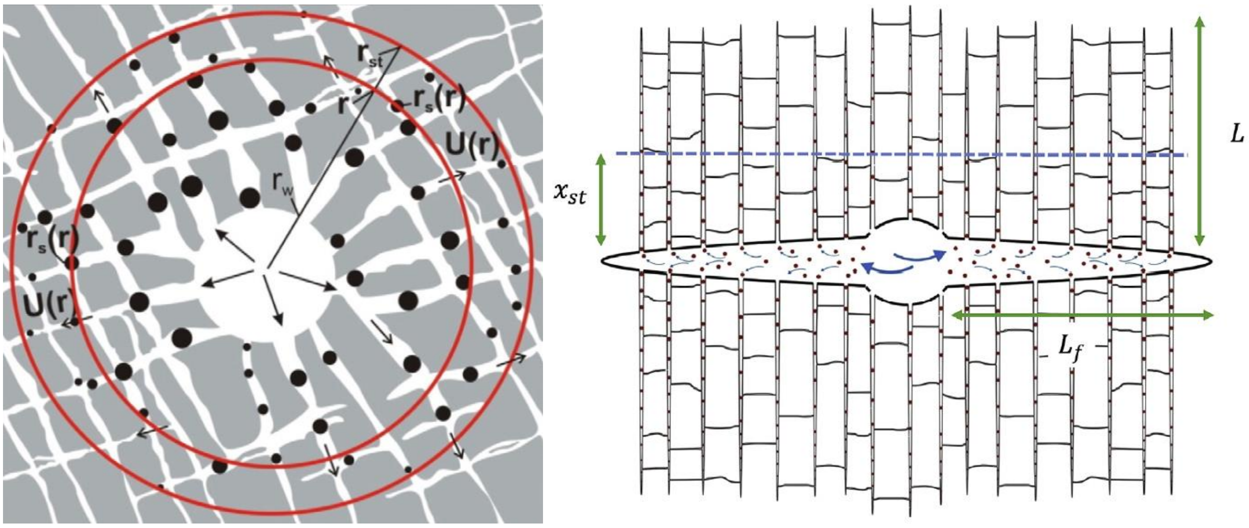



**Figure 6: Schematic representations of graded particle injection, showing (left) the relative movement of particles of increasing size (after Keshavarz, A., et al., 2014) and (right) its application in conjunction with hydraulic fracturing (after Keshavarz, A., et al., 2016)**

Finally, if these measures of better alignment with the high stress regime, reduction of near wellbore pressure loss, and controlling pressure dependent leakoff can be made more manageable, then current high viscosity, high temperature fluids used to manage these effects in the higher Cooper Basin thermal environment can be set aside for cleaner, lower viscosity fluids and improve fracture length, increased overall conductivity and a greater SRV. This has been a major change in North America, which Australia has not been able to implement because of our stress framework.

## CONCLUSIONS

We understand the problems of high stress magnitudes, NWBPL, and PDL and can counter them in some cases. In some cases, fracturing results are perplexing and produce low economic outcomes despite creating a large fracture area. In these cases, further steps such as inclined wells in the $\sigma_{HMax}$ direction as well as increased use of cleaner, low viscosity fluids and graded particle injection may be necessary to improve azimuth disorientation and increase the overall conductivity and SRV of the created fracture. These are challenges that face Australia and many high stress regions of the world in developing unconventional resources in those areas. The combined research funding of the US Department of Energy, Gas Research Institute and favourable tax considerations to operators in the 1990's was the great enabler to the establishment of unconventional resources in North America seen today. With increased funding and more favourable taxation consideration for the areas of applied research and development in the areas of hydraulic fracture experimentation, it is hoped that operators, state regulators, federal regulators, and research centres can team up to improve outcomes in this challenging and unique environment holding vast natural gas resources.

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