Thirty Seventh Symposium on the Geology of the Sydney Basin. Abstracts: Edited by A. Hutton, C. Ward and H. Bowman. May 6-7, 2010, Pokolbin, NSW, Australia.

3D GEOLOGICAL MODELLING AND CARBON STORAGE POTENTIAL OF THE SYDNEY BASIN

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ABSTRACT

The Sydney Basin contains Australia's largest concentration of stationary carbon dioxide emission sources, including power generation, oil refining and other industrial activities. For these emissions to be stored geologically capacity must be found within the geological sequence of the Basin, or adjacent basins.

A 3D conceptual geological model is presented, and used to make a preliminary estimate of carbon storage potential in the Sydney Basin. The model is built using the EarthVision suite of software tools (www.dgi.com). Information, used to constrain the conceptual model, included historical borehole reports, published geological conceptual basin cross sections, and published horizon top maps. The model seeks to represent the characteristics of the major sedimentary units and structures of the Sydney Basin. Rock properties crucial to fluid injection (porosity, permeability, temperature) are interpolated from the data available and modelled within the 3D geological framework.

A phase state model was calculated, using 3D grids of temperature and pressure values, to determine the location and extent of zones where supercritical conditions for CO_2 are met. Estimations of total pore volume within the supercritical zone indicate the theoretical capacity of the deep units is greater than that required to store the projected 20 year emissions of the Sydney Basin. The vast majority of this volume, however, may not be accessible due to low permeability at depth, and the fact that the centre of the Basin sits beneath urban development and national parks.

As only a small and scattered number of boreholes penetrate to the required depth, the interpretation could change dramatically with the addition of a small number of boreholes.

INTRODUCTION

Of the many methods proposed to tackle climate change, Carbon Capture and Storage (CCS) is unique in that it has the potential to allow the continued use of energy from coal while reducing greenhouse gas emissions. For CCS to be a success however, geological, social and economic factors must combine in such a way to allow the large scale drilling and injection that will be required. This paper details the use of 3D geological modelling in the site selection process at the basin scale.

For deep geological storage of carbon dioxide the gas must be kept in a supercritical phase. This maximises the density of the injected fluid, optimises storage capacity and limits the upward movement of CO_2. A depth of 800 m is widely used as an estimate of where the temperature and pressure conditions allow CO_2 to remain in the supercritical state (Bachu, 2003).

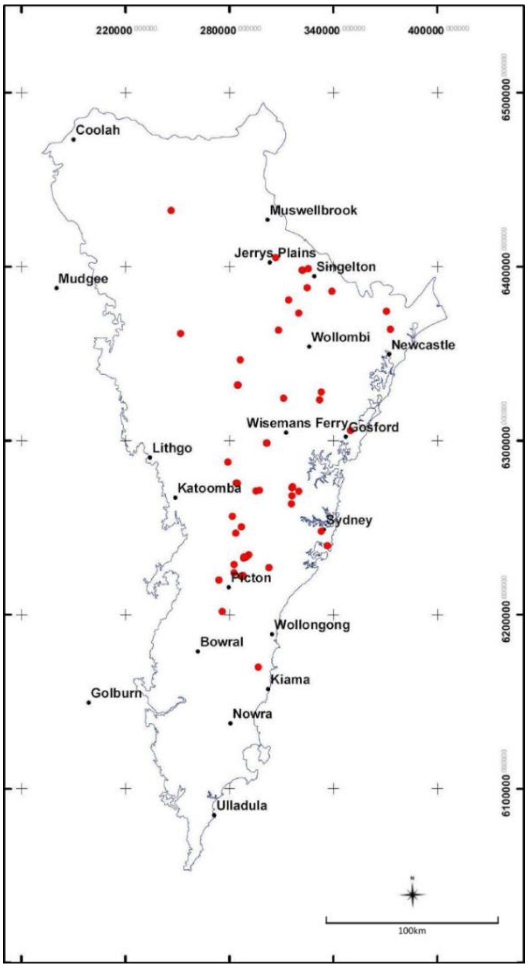

Figure 1: Location of borehole used in modelling process.

In the Sydney Basin only 49 boreholes extend beyond 800 m. The logs of these holes were extracted from the NSW Geological Survey database and collated by Dr. Saju Menacherry of the Cooperative Research Centre for Greenhouse Gas Technologies (CO2-CRC). Figure 1 shows the location of the boreholes used in the modelling process.

Given the scale of the Sydney Basin, it is obvious that the borehole data are inadequate to fix the shape of geological facies in 3D space if gridded without conceptual control. Therefore to build the basin scale 3D geological model the stratigraphy had to be simplified and the model constrained using additional geological information.

SYDNEY BASIN STRATIGARPHY SIMPLIFIED

The works of Herbert (1979), Branagan and Pedram (1990), Fergusson (2006), Glen (1993) and Herbert and Plimer (1989), among others, have contributed to the understanding of the stratigraphy and structural systems of the Sydney Basin.

Due to the size of the Sydney Basin, within each unit there are significant changes in the depositional environments, both north to south and east to west, and the details of all the units could not be incorporated into a large scale model. To produce a model that conforms to the geological constraints over the scale of the Sydney Basin and to maintain enough data to constrain the model shape a number of units were combined to create a simplified stratigraphic sequence. Units that have been shown to be continuous, or given different names in different areas, were combined. Table 1 shows the sequence used in the final model.

Table 1: Modelled merged units in stratigraphic order.

<table>
<tr><th>Period</th><th colspan="2">Group</th><th>Name</th><th>Data Points</th></tr>
<tr><td rowspan="3">Triassic</td><td colspan="2" rowspan="3"></td><td>Wianamatta Shale</td><td></td></tr>
<tr><td>Hawkesbury Sandstone</td><td>33</td></tr>
<tr><td>Narrabeen Group</td><td>17</td></tr>
<tr><td rowspan="5">Permian</td><td colspan="2">Singleton Supergroup</td><td>Late Permian Coal Measures (Illawarra, Newcastle, Tomogo)</td><td>1050</td></tr>
<tr><td rowspan="4">Shoalhaven Group</td><td rowspan="3">Maitland Group</td><td>Mulbring-Berry Siltstone</td><td>20</td></tr>
<tr><td>Nowra-Muree Sandstone</td><td>15</td></tr>
<tr><td>Branxton-Wandrawandian Siltstone</td><td>15</td></tr>
<tr><td>Upper Dalwood Group</td><td>Pebbly Beach-Rutherford Formation</td><td>7</td></tr>
<tr><td colspan="3"></td><td>Basement</td><td>29</td></tr>
</table>

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CONSTRAINING GEOLOGICAL INFORMATION

Our current conceptual understanding of the structure of the Sydney Basin is based on extensive surface mapping, gravity modelling, seismic lines, and borehole data. The surface expression of major faults and structures in the Sydney Basin is well documented. Memarian & Fergusson (2003) present a map showing the major structural features of the basin and their trends. This map was used as the basis for fault modelling. The dips assigned to the faults in the model were taken from the seismic data interpretation presented by Herbert & Pilmer (1989).

Leaman (1990) utilised gravity methods, calibrated over the Lachlan Fold Belt, the Bathurst Batholith and the Sydney Basin, to conclude that the base of the Sydney Basin is a continuation of the Lachlan Fold Belt, and dips to the east. To constrain the gridding of the basement data, the outcrop of the Lachlan fold belt, along the western edge of the Sydney Basin, as presented in the 1:250,00 geological map series (Sydney, S1 56-5, published 1966), was digitised and combined with borehole basement picks. This pooled basement data set resulted in the model successfully representing the easterly dip, with a central very open synclinal east-west axis.

Stewart & Alder (1995) published a contour map of the base of the Narrabeen Group, which represents the Permian Triassic boundary across the Sydney Basin. This horizon was used to constrain the gridding of the borehole data for all horizons tops. The contour map of the base of the Narrabeen Group was digitised, geo-referenced and used as the primary reference horizon in the EarthVision model. The gridding algorithm in EarthVision honours the borehole data for each unit, but uses weighted information from the reference horizon to constrain the interpolation between the boreholes. This gives the model a consistent form between horizons in areas of sparse data.

CONSTRUCTING THE 3D MODEL

In an EarthVision structural model, the faults are represented by 2D grids positioned in 3D space. Once the faults have been positioned their relationship to each other needs to be defined. EarthVision stores the interactions of faults in a ‘fault tree’. This information ensures that cross-cutting relationships and terminating faults are handled correctly. The surfaces built into the model as fault surfaces represent the Nowra monocline, Mt Murray monocline, Hunter dome, and the Lapstone structural complex (Figure 2).

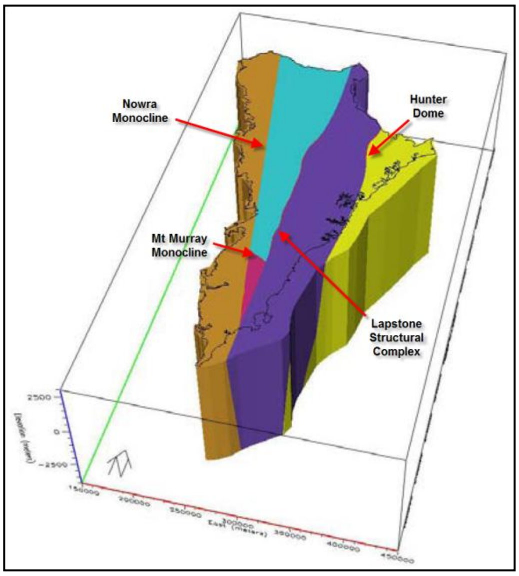

Figure 2: Fault block model of the Sydney Basin.

These surfaces confine the geological horizons (unit tops). A choice is made prior to gridding the horizons as to whether the horizons should be gridded in a geometrically restored space or gridded only within the bounds of each fault block. For this model the horizons were gridded in a geometrically restored space. All horizons for the Sydney Basin model were gridded using minimum tension, using the digitised Narrabeen Group base as the reference horizon. The resulting 3D structural model is shown in Figure 3. In Figure 4 the layers above the top of the Nowra-Muree Sandstone have been removed to display the shape and limited data used.

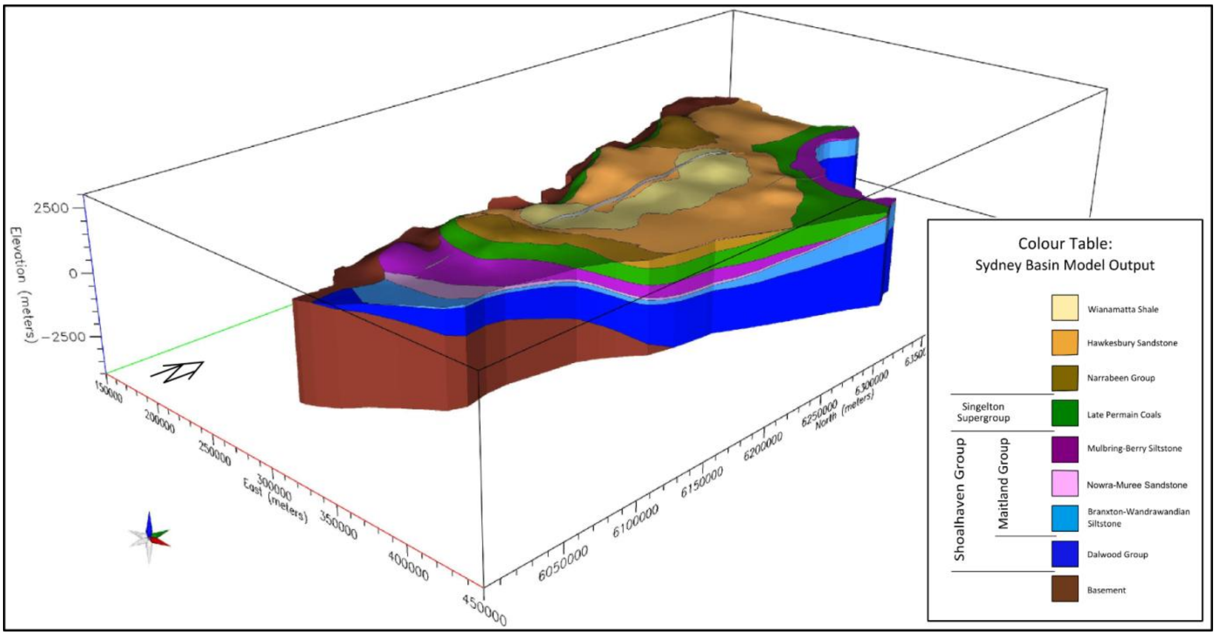

Figure 3: Sydney Basin geological structural model (Vertical exaggeration 1:15).

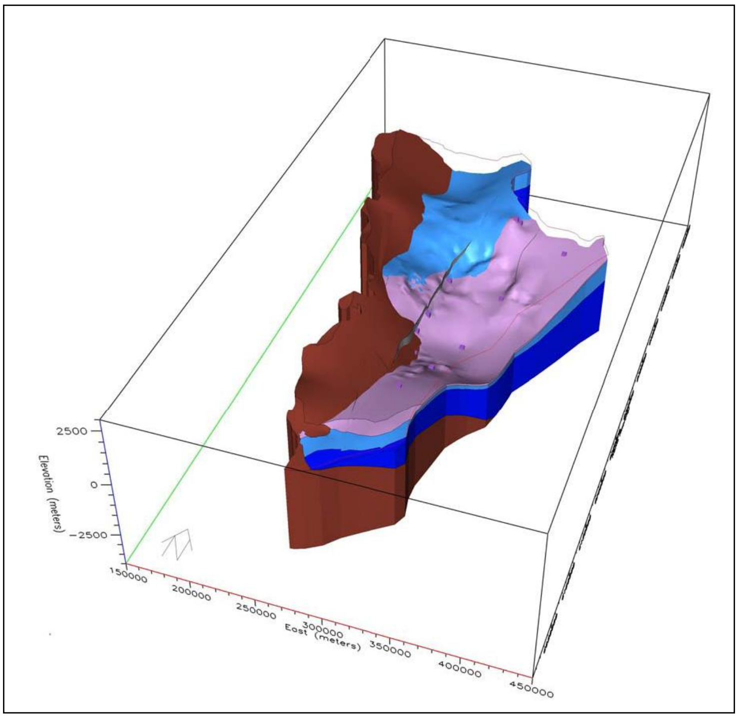

Figure 4: Sydney Basin geological model showing units from the top of the Nowra-Muree Sandstone to the basement. Borehole control for the top of the Nowra-Muree Sandstone are shown as dark purple cubes.

For each unit the porosity and permeability data were gridded using minimum tension. The porosity model for the Nowra-Muree Sandstone unit is shown in Figure 5. Porosity increases from very low values (< 0.1) in the north-east to higher values in the south-west (0.18 with bore control). The higher values modelled in the far south-west are extrapolated beyond the data range.

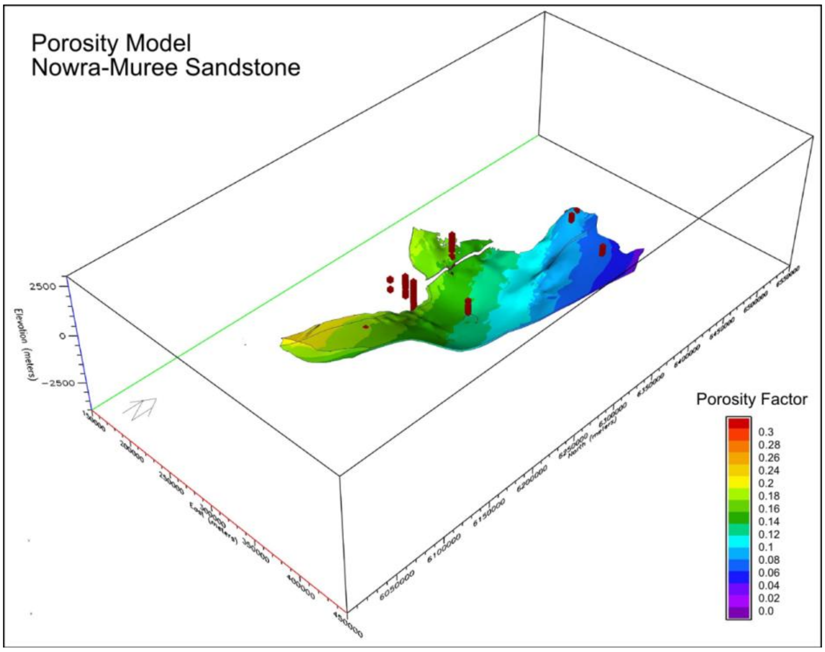

Figure 5: Porosity modelled within the Nowra-Muree unit. Borehole data points are shown as red cubes.

Bachu (2002) outlines a method for creating a 'phase space' for calculating CO_2 injection potential. This calculation requires the pressure and thermal gradients to be known. For the CO_2 phase calculation the temperature data collected and published by Jaworska (2008) were modelled using a liner temperature gradient with depth. The EarthVision formula processor was used for the CO_2 phase calculation considering both hydrostatic and lithostatic pressure conditions in conjunction with the structural model. In Figure 6 the intersection of the CO_2 phase state model with the Nowra-Muree Sandstone unit is shown.

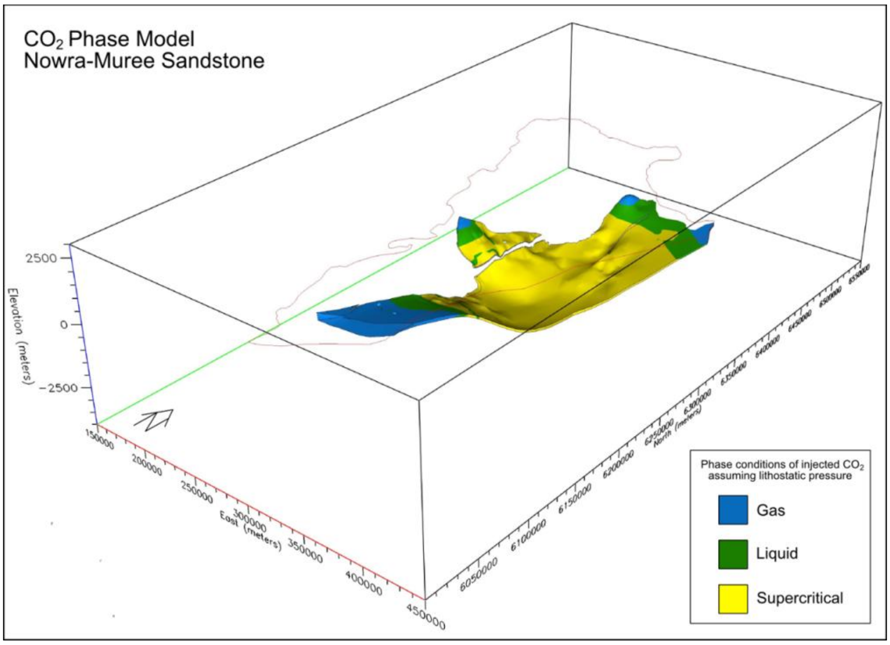

Figure 6: Intersection of the phase state model and the Nowra-Muree Sandstone unit.

VOLUME ESTIMATES

The results of volumetric analysis of the 3D geological model are shown in Table 2. The Nowra and Muree sandstones have been highlighted in previous work as having the greatest potential for gas storage (Patchett & Langford, 2005). It can be seen that 63% of the Nowra-Muree Sandstone falls within the supercritical zone, assuming lithostatic pressure. Applying the porosity model as a factor to each cell within this volume returns a total pore volume of $1.10x10^{11}$ m^3.

Assuming a density of supercritical CO_2 of 700 kg/m3 (IPCC, 2005), and using the pore volumes from the model, the upper limit of the mass of CO_2 that can be stored in each unit can be estimated. These values are presented in Table 3. According to Bradshaw et al. (2005), these values represent the theoretical capacity of the modelled units. From these calculations the Nowra-Muree Sandstone could hold 77,102 Mt of CO_2. This value compares favourably to the 1336 Mt of CO_2 estimated to be emitted in the Sydney Basin over the next 20 years (Bradshaw, 2005). These figures reflect pore space alone, and do not take into account permeability. The current dataset suggests that permeability (0 to 6 mD bellow 500m) will be a limiting factor in any injection scheme. More data are required before injectability can be gauged.

Table 2: Total pore volume of modelled units and pore volume under supercritical conditions

	Pore Volumes (m^3)		
		Pore volume @ Supercritical conditions	
UNIT	Total Pore Volume	Lithostatic	Hydrostatic
Hawkesbury Sandstone	4.46E+11	4.74E+06	0.00E+00
Narrabeen Group	1.66E+12	1.34E+11	2.81E+10
Late Permian Coal Measures	2.28E+12	8.24E+11	6.83E+11
Mulbring-Berry Siltstone	8.13E+11	3.89E+11	3.63E+11
Nowra-Muree Sandstone	1.93E+11	1.10E+11	1.05E+11
Branxton-Wandrawandian Siltstone	1.04E+12	7.38E+11	6.97E+11
Pebbly Beach-Rucherford Formation	1.96E+12	1.49E+12	1.49E+12
Sedimentary Sequence	8.40E+12	3.68E+12	3.36E+12

Table 3: Theoretical supercritical storage capacity of modelled units

Total pore volume expressed as Mt of CO_2 *		
	Potential CO_2 storage (Mt)	
UNIT	Lithostatic	Hydrostatic
Hawkesbury Sandstone	3	0
Narrabeen Group	93,790	19,680
Late Permian Coal Measures	577,050	478,119
Mulbring-Berry Siltstone	271,999	253,839
Nowra-Muree Sandstone	77,102	73,354
Branxton-Wandrawandian Siltstone	516,530	488,028
Pebbly Beach-Rucherford Formation	1,042,622	1,042,267
Sedimentary Sequence	2,579,096	2,355,286

* (assumes a density of CO_2 of 700 kg/m3)

CONCLUSION

Using a combination of borehole data and conceptual information (from maps, cross sections and outcrop observations), a 3D geological structural and property model of the Sydney Basin has been constructed. This model provided a suitable framework for estimating the CO_2 storage potential of the Sydney Basin. The 3D model gives a more rigorous structural representation and volumetric estimate compared to the use of averages and geometric factors, suggested in Gibson-Pool et al. (2008).

On the basis of porosity, volume and depth, the most promising unit is the Nowra-Muree Sandstone. With an estimated capacity of 77,000 Mt of CO_2, this unit alone could hold the 1336 Mt projected to be produced in the Sydney region over 20 years. However, the proportion of this unit available for injection is significantly reduced when permeability, faulting, land use and economic factors are also considered.

The lack of representative permeability data prohibits the calculation of any storage indicator other than total pore volume. The same limitations were faced by Blevin et al. (2005) who also concluded that permeability data was a limiting factor in characterising the Sydney Basin.

This work has demonstrated the capacity of 3D geological modelling as a suitable environment for making CO_2 estimates. To date there is a paucity of necessary data at the critical depths of investigation. As more data are made available the model developed here could be updated and improved estimates of carbon capture and storage potential of the Sydney Basin provided.

Acknowledgements

We would like to thank Mr Gary Johnston for his donation to the UNSW Connected Waters Initiative which funded the purchase of the EarthVision license used for this project.

We would also like to thank Professor Col Ward for his guidance in the early stages of developing the 3D geological model.

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