Coupling Petrography and Seismic Attributes for Locating Permeable Zones in the Cooper Basin/South Australia, a Possible Workflow for Geothermal Projects.

Hani Abul Khair
Hani.abulkhair@adelaide .edu.au

ABSTRACT

Hutton sandstone in Celsius-1 and Burley1, 2, 3 were studied both under thin sections and using seismic attributes for reservoir characterization. Hutton sandstone in Celsius-1 showed extensive quartz cementation in the form of overgrowth composing a percentage of around 50% of the overall rock volume. This quartz cement caused strong reduction in porosity and permeability. Several diagenetic processes such as authigenic muscovite formation in the pore spaces and pressure solutions indicated that the rock was subjected to temperatures up to 295 C. Wells close to Celsius-1 (e.g. Burley-1, 2, 3 located 4 km from Celsius-1) show no quartz cementation or high temperature diagenetic processes. Thus, vertical or horizontal migration of hot fluids can explain high temperature diagenesis variation between Celsius-1 and the adjacent wells.

I calculated 2D seismic attribute (e.g. reflection intensity, relative acoustic impedance, envelope, and sweetness) for the seismic sections passing through Celsius-1 and compared it to the same attributes in adjacent wells. Some attributes showed different rock elastic properties of the Hutton sandstone in Celsius-1 compared with the near wells. This indicated the ability of using commercial seismic attributes for locating porous and permeable zones.

INTRODUCTION

Cooper Basin in Southern central Australia is a region of high geothermal gradients (Cull and Denham, 1979; Cull and Conley, 1983; Somerville et al., 1994; Gerner and Hogate 2010) (Figure 1). This anomalous area is part of a regional high heat flow anomaly that was attributed by some researchers to enrichment of radiogenic elements within the Proterozoic basement (e.g. Sass and Lachenbruch, 1979; McLaren et al., 2003).

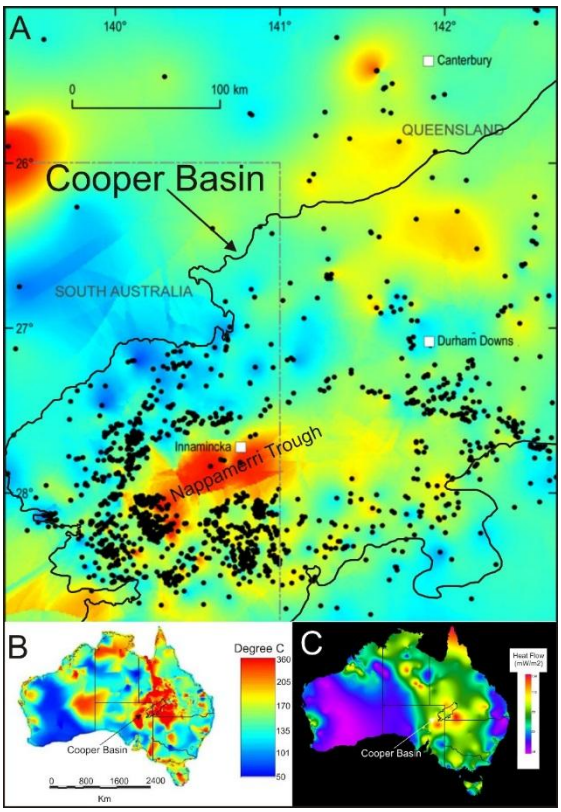

Figure 1: Map of predicted temperatures at 5 Km depth in the Cooper Basin (A), and across Australia (B) (Gerner and Hogate, 2010), scale bar applies to the main image. Black dots are wells from which temperature measurements were taken. Also shown surface heat flow across Australia (C) (from Hot Dry Rocks Pty Ltd).

Studying the diagenetic history of hot sedimentary aquifers (HSA) is essential to determine their feasibility as targets for geothermal projects. Diagenesis of

sedimentary rocks exist at temperatures and pressure less than that required for metamorphism. They can destruct or enhance porosity and permeability. High pressures exerted during tectonic activities cause alteration and/or recrystallization of certain minerals which affect the overall mineral volume, and thus porosity. Whereas, strong chemical reactions driven by hot fluids moving within a reservoir can cause dissolution and redistribution of mobile elements.

Diagenetic processes can be studied in polished thin sections under the polarized microscopy, scanning electron microscopy (SEM), or Cathodoluminescence. I studied the available core and cutting thin sections in the north east part of the Cooper Basin and compared the results with some commercial seismic attributes. The study focused at the Hutton sandstone as a target HSA in the Cooper Basin especially in the area of Celsius-1 and the adjacent wells (Figure 2).

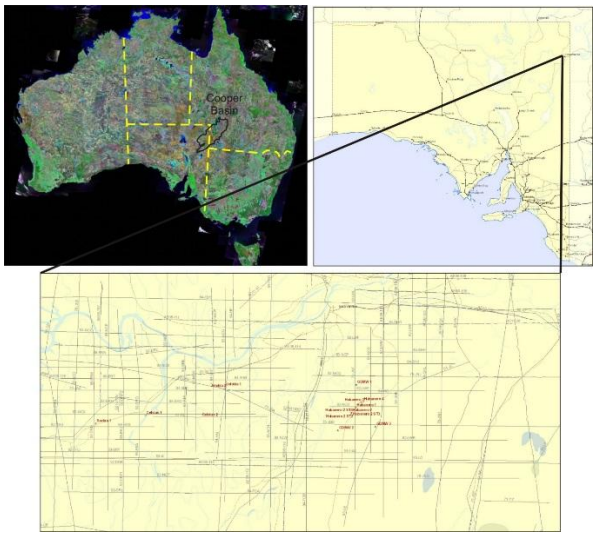

Figure 2: Location of the study area including the geothermal wells Celsius-1, Burley-1, 2, and 3.

SEISMIC ATTRIBUTES

A seismic attribute is a quantitative value measuring a seismic characteristic. Spatial change in any reservoir characteristic will affect the reflected seismic wave characteristics. The quantitative measuring of specific seismic signal characteristics leads to understanding the reservoir density and porosity. 2D and 3D volumetric seismic attributes have proven to be amongst the most useful geophysical techniques for reservoir characterization. I calculated attributes at seismic sections crossing the target wells within the study area and compared the results at the Hutton sandstone depth.

Four types of seismic attributes (i.e. reflection intensity, relative acoustic impedance, envelope, and sweetness) were used to compare the seismic signal response in Celsius-1 area with adjacent wells at the depth of Hutton sandstone. Reflection intensity is the average amplitude over a specified window (9 samples) multiplied with the sample interval. Reflection Intensity is useful for the delineation of amplitude features while retaining the frequency appearance of the original seismic data (Figure 3).

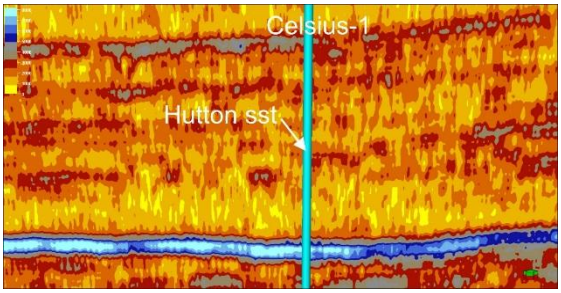

Figure 3: Reflection intensity measured along a seismic section that run through Celsius-1.

Relative acoustic impedance is a running sum of regularly sampled amplitude values. Calculated by integrating the seismic trace, passing the result through a high-pass Butterworth filter, with a hard-coded cut-off at (10*sample rate) Hz. This attribute shows apparent acoustic contrast, indicates sequence boundaries, unconformity surfaces and discontinuities. It can also indicate porosity or fluid content in the reservoir. Envelope is the total instantaneous energy of the analytic

signal (the complex trace), independent of phase. Also known as 'Instantaneous Amplitude', 'Magnitude' or 'Reflection strength'. The envelope attribute is of importance detecting bright spots caused by gas accumulations, detecting major lithological changes that are caused by strong energy reflections and sequence boundaries. Sweetness is the implementation of two combined attributes (Envelope and Instantaneous Frequency) and is used for the identification of features where the overall energy signatures change in the seismic data.

DIAGENESIS

Hutton sandstone in Celsius-1 showed diagenetic processes responsible for porosity and permeability reduction. Authegenic muscovite filling pore spaces, undulose extinction of quartz grains, pressure solutions, quartz cementation with a total of 50% of the whole rock, and kaolinite alteration to illite are all diagenetic processes indicate that Hutton sandstone was subjected to high temperature and pressure (Figure 4). Paleo-temperatures of Hutton sandstone in Celsius-1 area reached up to 295 C according to the temperature of the formation of authigenic muscovite. Alteration of kaolinite to illite usually happens at a temperature ranging from 225-350 C. Whereas quartz undulose extinction exists at a depth of around 2500 m.

However, feldspar dissolution and alteration to clay minerals in Burley-1, 2, and 3 enhanced the porosity and permeability of the same formation (Figure 5). Despite the fact that the wells are not far from each other, a major factor resulted in extensive diagenetic processes within Hutton sandstone in Celsius-1 compared with adjacent wells. Calcite cementation was found in some areas reducing porosity.

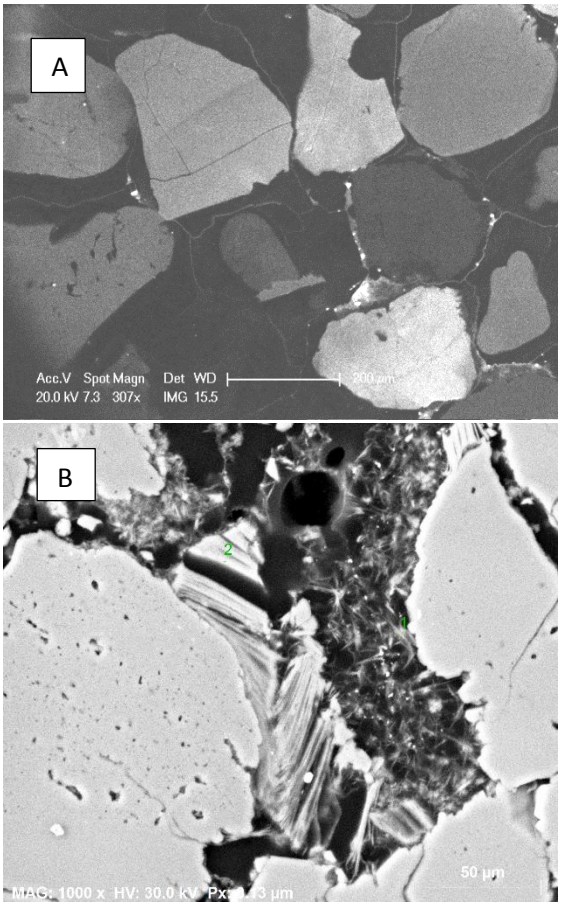

Figure 4: A= Cathodoluminescence showing quartz over growth in Celsius-1, B= SEM showing authigenic muscovite filling the pore space.

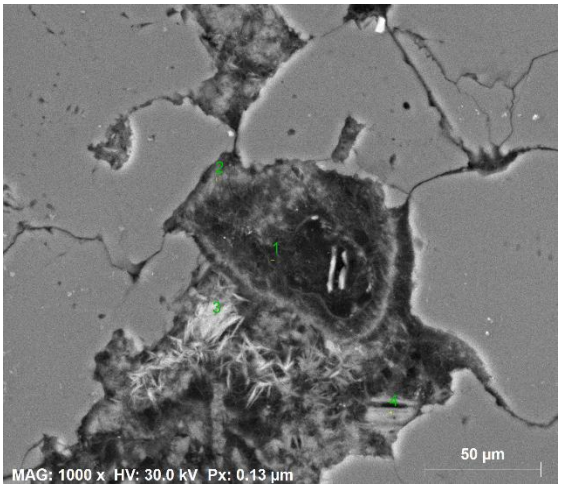

Figure 5: SEM showing feldspar grain (number 1) undergoing dissolution.

SUMMARY

Comparing the diagenetic processes existing within the Hutton sandstone of Celsius-1 with those of adjacent wells showed a clear evidence that the formation was subjected to high temperatures and pressures in the Celsius-1 area. This can be interpreted as a result of original high permeability allowed the hot solutions to pass through the formation and cause these diagenetic processes in this preferred area. Other explanation might be a vertical movement of hot solution from buried granites due to fault that form conduit for fluids. Although the 2D seismic sections don't show any fault in the Celsius-1 area, the low quality of the seismic raise the question of whether or not they are representative of the actual structures. Thus, better quality 2D or most preferred 3D seismic survey should be conducted.

Diagenetic processes including recrystallization and cementation cause solidification of the reservoir. Quartz overgrowth was found in Celsius-1 at the depth of Hutton sandstone causing reduction of porosity and permeability and increasing density of the reservoir rock. Whereas feldspar alteration and/or dissolution enhanced the porosity of the same formation in wells Burley-1, 2, and 3 and thus reduced density. Seismic attributes, such as acoustic impedance, reflection intensity, envelope, and sweetness are tested in this study against diagenesis results. A fair to good correlation was found between highly quartz cemented reservoirs and the reflection intensity. While relative acoustic impedance correlated very well with increased porosity by feldspar dissolution both from thin sections and well logs. Thus, seismic attributes can be used directly as indicators on reservoir density and porosity. Envelope and sweetness showed fair relation with reservoir density.

In general, after comparing all these attributes with reservoir quality, fair to good correlation between diagenetic processes and seismic attributes can be seen.

ACKNOWLEDGMENT

The author would like to acknowledge the appreciated financial contribution and provision of the data from the Petroleum and Geothermal division of The *Department for Manufacturing, Innovation, Trade, Resources and Energy* (*DMITRE*) / PACE 2020. Also, I would like to acknowledge the financial support of The *South Australian Centre for Geothermal Energy Research* (*SACGER*).

REFERENCES

Cull, J.P. and Conley, D., 1983. Geothermal gradients and heat flow in Australian sedimentary basins. *Bureau of Mineral Resources, Journal of Australian Geology and Geophysics*, 8: 329-337.

Cull, J.P. and Denham, D., 1979. Regional variations in Australian heat flow. *Bureau of Mineral Resources, Journal of Australian Geology and Geophysics*, 4: 1-13.

Gerner, E., and Holgate, F., 2010. *OzTemp – Interpreted Temperature at 5 km Depth.* Geoscience Australia, Canberra.

McLaren, S., Sandiford, M., Hand, M., Neumann, N., Wyborn, L. and Bastrakova, I., 2003. The hot southern continent; heat flow and heat production in Australian Proterozoic terranes, in: Hills, R.R. and Mueller, D.R. (Eds) Evolution and dynamics of the Australian Plate. *Geological Society of America Special Paper*, 372: 157-167.

Sass, J.H. and Lachenbruch, A.H., 1979. Thermal regime of the Australian Continental Crust, in: M. W. McElhinny (ed.) *The Earth: its origin,*

structure and evolution. Academic Press: London, pp 301-351.