The Western Australian Geothermal Centre of Excellence

Klaus Regenauer-Lieb, Hui Tong Chua, Xiaolin Wang, Frank Horowitz, Florian Wellmann, Florian Fusseis, Thomas Poulet, Heather Sheldon, Mike Trefry, Klaus Gessner, Paul Wilkes, Thomas Hoskin, Simone Seibert, Peter Cawood, Steve Reddy, Moyra Wilson, Noreen Evans, Nick Timms, Chris Clarke, Geoff Batt, Oliver Gaede, Brent Mc Innes, Sean Webb, James Cleverley, Mehroz Aspandiar, Martin Danisik, Arcady Dyskin, Elena Pasternak, Ali Karrech, David Healy, Neil Prentice, Tim Shannahan, Charlie Thorn, Steve Harvey and Mike McWilliams

Western Australian Geothermal Centre of Excellence , UWA-CSIRO-CURTIN
ARRC 29, Dick Perry Avenue 6151 Kensington WA, PO Box 1130, Bentley WA 6102

In February 2008 the WA Government announced investment into the Western Australian Geothermal Centre of Excellence with co-funding from CSIRO, UWA and Curtin University. The Centres mission is to underpin a new era of energy development; to provide excellence in geological understanding and exploitation of geothermal fields; to foster a capable work force for the geothermal industry by providing world class training to students in geothermal energy systems and to promote the development of “geothermal cities”.

The Centre establishes capacity for the Australian industry to lead the exploration and exploitation of geothermal heat in a modern society. By exploring for and utilising low-grade heat in a permeable sedimentary environment the Centre addresses an overlooked opportunity for broadening the footprint of geothermal energy utilisation. We are particularly focussing on the geological setting of sedimentary basins like the Perth Basin, where exploitable heat is available right where it can be used. We suggest that geothermal groundwater in such basins provide a unique opportunity for the Australian geothermal industry. Owing to the high natural permeability there is no need for artificial hydraulic fracturing.

The Centre consists of the constituent institutions in Perth. Its researchers will provide relevant expertise in numerical modelling, geophysics, geology, geochemistry and engineering. The numerical modelling team will build the Australian capability for geothermal modelling. It will draw on the existing expertise of the CSIRO fluid/solid mechanics and reactive flow modelling group. With 25 researchers this group is the largest such group internationally and well respected in the hard rock mining community. However, it is currently overlooked in the emerging Australian geothermal sector. Modellers from this group will participate in the Centre and nucleate cross-fertilisation between the geothermal and mining communities.

The geophysical aspects of the research consist of a collaborative CSIRO-UWA-CURTIN team. The structural geology/ hydrogeology/ microstructure/ geochemistry will be performed through an existing Curtin-UWA-CSIRO collaborative team of ten researchers including personnel from the John de Laeter Centre. This interdisciplinary team will be unique in its breadth.

The above-ground engineering aspects will be led from the UWA Mechanical Engineering Department in strong collaboration with Earth Scientists from the other institutions. These researchers are focussing on novel exploitation technologies for low-grade heat. This is an essential step for broadening the utilisation opportunities of geothermal energy in the metropolitan urban environment. We investigate zero emissions Heating Ventilating and Air Conditioning (HVAC) technologies and geothermal desalination. Our aboveground strategy is complementary to the Queensland engineering based State Centre, which focuses on electricity generation and hot rock technologies.

Keywords: Geothermal Exploration, Deep Sedimentary Targets, Modelling and Simulation, Structural geology, Hydrogeology, Geochemistry, HVAC Direct Heat Use, Desalination

Geothermal Basin Exploration

Many of Australia’s major cities are built on sedimentary basins with naturally hot aquifer systems at shallow depth, often less than 3 km depth. Permeabilities can be extremely high making them an ideal target for geothermal energy extraction.

Classically sedimentary basins are investigated for petroleum exploration and a great host of knowledge exists for this field. In our COE we acknowledge the fact that petroleum geosciences only allows us to provide a first cut at geothermal exploration. There are two main reasons for this: 1) Economic constraints demand that geothermal exploration must do better than petroleum exploration because geothermal drilling cannot afford a ratio of one successful drillhole out of seven drilling projects. 2) Geothermal targets are deep aquifers. In the petroleum geoscience it is not standard to think of deep aquifers as potential targets. Consequently heat transferred through water motions in these deep aquifers is generally neglected. Petroleum geoscience consider sophisticated approaches for thermal/sedimentary evolution modelling of sedimentary basins. In these models heat is thought of being transferred only through conduction or through tectonic movements of rock masses and little attention is paid to the possibility of fluid heat transfer.

This assumption squarely contradicts current geothermal practice where hydrogeology has been used as the science to focus better on the flow in hot aquifers. This approach has been used successfully in many places for the calculation of geothermal extractions for district heating systems such as those in the municipalities around Munich (Germany) where a hot aquifer in the Molasse Basin is the target at 3 km depth. Judging from such successful geothermal practice hydrogeological modelling appears to be at first sight the preferred method for geothermal. However, hydrogeology falls short in the science of dealing with geological faults, 3-D complexity and in particular the possibility of geothermally driven convection.

While clearly there is merit in marrying the sciences of petroleum and hydrogeology the basic underlying assumption of hydrogeology is still topography driven flow. In such models water follows the underground topography driven by its buoyancy defined by heat content and salinity. Hydrogeological software packages therefore are not designed for dealing with true 3D aspects but they are excellent for inherently layered aquifers extruded into 3-D. In addition hydrological models tend to overlook the possibility of thermally driven convection. There are a number of numerical codes that are designed for true 3-D geothermal flows and these would appear to be the preferred tool for assessing geothermal prospects. However, these codes have been mainly used in volcanic targets. A present shortcoming is that the 3-D complexity of sedimentary basins demands implementation on supercomputer systems, which is not widely available to date.

Using the example of the Perth basin we overcome this shortcoming and develop a workflow for geothermal modelling of geothermal flows in sedimentary basins, which we will lay out in the following subsections. The workflow consists of a straight coupling between structural geological modelling, regional numerical fluid flow modelling, reservoir scale modelling and geophysical inversion. Geophysical inversion is used to dispatch the loop of structure and fluid flow modelling for matching geophysical and geological data. A more detailed description of the first part of the workflow can be found in a companion abstract (Wellman et al., this volume).

3-D structural Modelling of the Perth Basin

The Perth Basin is a half-graben system to the west of the Darling Fault extending into the marine basin to the west. It comprises permeable sedimentary rocks down to 10-15 km depth, and is deeply dissected by normal faults. The structure of the basin is known through seismic and other geophysical and drillhole data. A 3-D structural model is compiled from these data using software packages such as Geomodeller or Gocad. This model serves as a basis for groundwater flow and convection modelling. The aim is to incorporate multiscale observations of sedimentology and structural characteristics, ranging from micro-scale CT scans up to field observations. By way of example we show a structure model (Figure 1) constructed for the Harvey ridge structure in the South Perth Basin built by Thomas Hoskin and Florian Wellmann. This model is based on a database using seismic, borehole, gravity, magnetic and structural data. This structure is close to the southern industrial precinct developed around Bunbury and a potential site for a CO_2 sequestration.

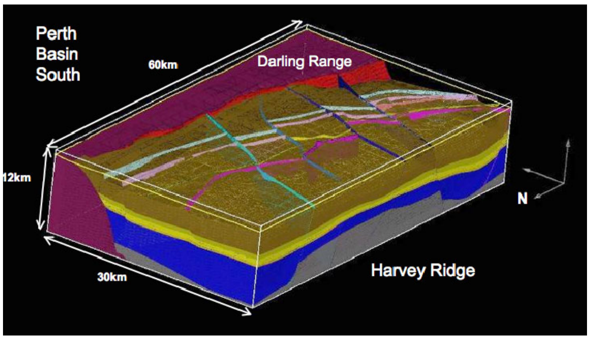

Figure 1 showing the Harvey Ridge structure in the southern part of the Perth Basin. Basement shown in grey, blue is Permian sediments, above the blue layer is the potential target for CO_2 sequestration.

3-D Numerical Regional Modelling of Fluid Flow and Heat Flow

The Perth basin comprises sediments of highly variable permeability ranging over several orders of magnitude from milli-Darcys to Darcys at several km depth. The Yarragadee aquifer is one of the largest fresh-water aquifers in the world, which is currently used to supply drinking water to metropolitan Perth. At greater than 1 km depth the temperature is too high for drinking water use (>50°C). The greater depth is the proposed target for extracting geothermal heat. The regional numerical flow modelling will use numerical models to explore the potential for fluid flow driven by heat, salinity and topography. The aim is to identify thermal upwellings and downwellings in the Perth Basin, which may be used for geothermal heat extraction/injection.

3-D Reservoir Scale Modelling

The exploitation of low-grade heat from shallow to intermediate depth aquifers is a new research field pioneered by the WA Geothermal Centre of Excellence. We intend to harness 90°C hot water for direct heat use applications, and re-inject water at ~40-50°C into the aquifer. There is no net water abstraction. The flow rate required for air conditioning large new housing developments (e.g. 10 000 homes ca. 100 MWth base load) can be substantial and far in excess of 100-200 litres per second that are presently achieved in the water extraction bores from the aquifer. It will require an array of injection and extraction holes into the permeable Yarragadee aquifer. We will use reservoir engineering to optimise the layout of these wells using a novel approach for which a provisional patent is filed. This approach goes beyond the classical geostatistical modelling and will assimilate the outcomes of the structural, inverse and fluid flow modelling being conducted in the COE.

Geophysical Inverse Modelling

The structure of the Perth Basin is complex and not well constrained, particularly in the metropolitan area where seismic data is lacking. A detailed knowledge of the structure is required to reduce risk in exploring for geothermal heat resources. The aim of this project is to use inverse modelling techniques to refine the structural model of the Perth Basin as new data become available within the COE, e.g. from drilling and forward modelling of fluid flow. A software platform will be developed to enable calculations before drilling, and on-site data assimilation and inversion while drilling. This is in close collaboration with the CAGI (computer-aided geological inversion) initiative of CSIRO, Intrepid, BRGM, GA and UBC built around Geomodeller.

Deep Heat

This program is aimed at collaboration with the wider Australian industry and research activities focussing on high temperature geothermal activities, which is not an immediate target for the Western Australian Geothermal Centre of Excellence. We offer our leading capacity in solid mechanics, specifically for calculating high temperature fractures and high strain shear zones. We also supply our leadership in high temperature fluid dynamics, specifically chemically reactive flows, and contribute the outstanding geochemical facilities of the State Centre of Excellence John de Laeter Centre. We integrate this work with the Perth Basin by looking at the potential signature of higher temperature (paleo) systems in the Perth Basin. Extracting heat from these deeper and higher temperature systems requires an understanding of rock mechanics in the brittle-ductile transition, which is identified as the key problem in extraction of heat from “hot rock” geothermal systems. The two subprograms of the Deep Heat initiative are :

Identification of deep heat and its geochemical fingerprinting

This subprogram uses geochemical tools to define the thermal history of the Perth Basin. The mineralogy and isotopic signature of authigenic clay minerals within the basin sediments will be combined with low-T thermochronological analysis of basin sediments through (U-Th)/He and fission track dating of apatite samples to provide direct constraint of post-depositional thermal history within the temperature range relevant to geothermal circulation. This combination of analyses should be able to identify temperature variation and excursions of less than 30°C, revealing significant detail on the magnitude and temporal evolution of paleo-geothermal systems within the basin. Modelling of this geochemical data will also allow us to increase the robustness of the chemical simulation outlined in the other programs. This work will require the extraction of appropriate borehole sample materials from sandstone and siltstone units whose relationships to basin architecture can be well constrained through seismic data. $^{3}He/^{4}He$ analysis of deep fluids extracted from boreholes may also allow explicit constraint of fluid residence time in the aquifer.

Extraction of deep heat

One of the biggest challenges for the exploitation of deep geothermal power is understanding and enhancing the permeability structure at great depth. It was not the lack of heat that caused failure of the first Hot Dry Rock projects in Los Alamos and Cornwall, but the lack of pervasive permeability. We have now a lot of observations of high local permeabilities down to 9 km depth (e.g. the KTB borehole in Germany); however, we still lack understanding of what allows high permeability to exist at such high temperatures and pressures.

This subprogram targets just this problem from empirical and computational approaches. The computational approach is based on a recently developed thermodynamic formulation which allows for the first time to predict fracturing at high temperature in the brittle-ductile transition zone (Regenauer-Lieb et al., 2006). The approach predicts that most high temperature geothermal drillholes reach a depth where brittle and ductile processes are likely to compete. This critical temperature depends on rock composition (rheology), the loading rate and the presence/absence of fluids. For granite the critical temperature is of the order of ~270 °C in compression and ~230°C in extension (Figure 2).

We will pursue the fracture of hot granite and benchmark the predicted shear zones on the basis of available deep drillhole data including microstructural observations.

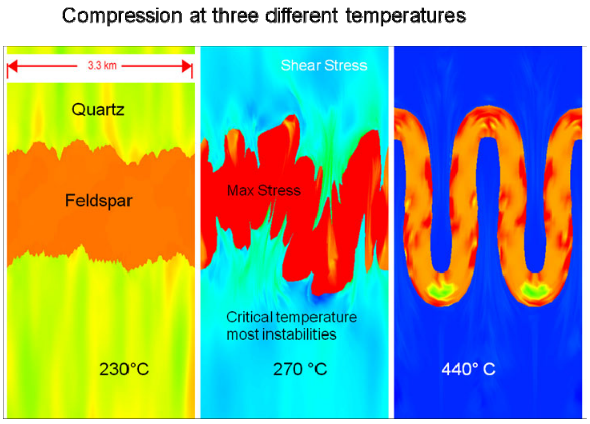

Figure 2 Numerical models of an isothermal quartz-feldspar composite slab with random thermal perturbations shortened from an initial configuration of 13.2 x 3 km to a final configuration of 3.3 x 12 km.

The empirical approach will assess the deeper Perth Basin and its likely basement to provide an assessment of the areas with deep geothermal potential. Microstructural analysis, utilizing scanning and transmission electron microscopes, X-Ray CT scans and a variety of other methods are used to examine competing deformational processes in rocks: for example the sliding of grains past each other and the formation of cavities along heterogeneous grain boundaries. The possible coupling of these mechanisms and their relation to fluid flow in deforming rocks is inferred from compositional and orientation variations in mineral grains. To this end we investigate these processes using bright X-Rays from a synchrotron source. Such sources can identify and map the 3-D connectivity of micro-sized microporosity (Figure 3). These studies are highly relevant to the high temperature shear zones modelled in Figure 2 because the microporosity under study serves as the nucleating damage for the larger scale high temperature flow of rock.

Above ground Technology

The above ground technology investigated in the Western Australian Geothermal Centre of Excellence has been the subject of the first AGEC presentation (Regenauer-Lieb et al., 2008) and shall not be repeated here. At present we focus on geothermal desalination (in cooperation with National Desalination Centre at Murdoch University) and geothermal air conditioning and cooling using geothermal fluids harvested in the Perth Basin.

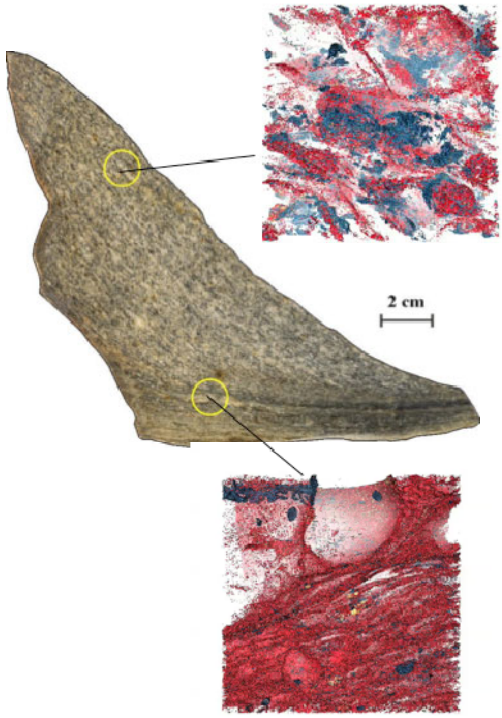

Figure 3 Hand specimen (Redbank Shear Zone) exhibiting a strain gradient from top to bottom. Representative sample series investigated by synchrotron (1.3 μm resolution) X-ray tomography are shown. Red is pore space, blue is mica and feldspar and quartz are rendered transparent. A dynamic mechanism for pumping of fluids through the shear zone centre has been identified (Fusseis et al., 2009)

Summary

We have described a tightly integrated research program for investigation of the Perth Basin Geothermal opportunity. We are particularly excited by the opportunity of intermediate to low temperature geothermal systems to contribute towards a zero emission energy supply.

References:

Fusseis, F., Regenauer-Lieb, K., Liu, J., Hough, R. and deCarlo, F., 2009. Creep Cavitation can establish a granular fluid pump through the middle crust Nature, 459: 974-977.

Regenauer-Lieb, K., Chua, H., Wang, X., Horowitz, F. and Wellmann, F., 2008. Direct-Heat Use for Australia, Australian Geothermal Energy Conference. AGEC.

Regenauer-Lieb, K., Weinberg, R. and Rosenbaum, G., 2006. The effect of energy feedbacks on continental strength. Nature, 442: 67-70.

Wellman, F, Horowitz, F, Regenauer-Lieb, K., Concept of an Integrated Workflow for Geothermal Exploration in Hot Sedimentary Aquifers, (this volume)