HOT ROCK LIMITED

The Case for Hot Sedimentary Aquifer (HSA) Geothermal in the Otway Basin

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Introduction

§ **Hot Sedimentary Aquifer (HSA) geothermal resources, in the Otway Basin (OB), are still being overlooked as one of the most compelling means for moving geothermal production forward in Australia.**

§ **This paper details the case for HSA developments in the OB based on:**

- § Abundance of HSA resources
- § Shallow depths to commercial grade temperatures
- § The absolute need for good permeability
- § The specific geologic setting of the OB which provides good potential for both primary permeability in clean quartz sands at shallow depths, and secondary permeability in fractures at depth
- § Highly successful development of HSA geothermal resources overseas

§ **A government – industry – research sector collaboration for a two well proof of concept drilling, testing and pilot plant program at the Koroit HSA project is being pursued by Hot Rock Limited (HRL) as the key means for moving forward to achieve commercial success.**

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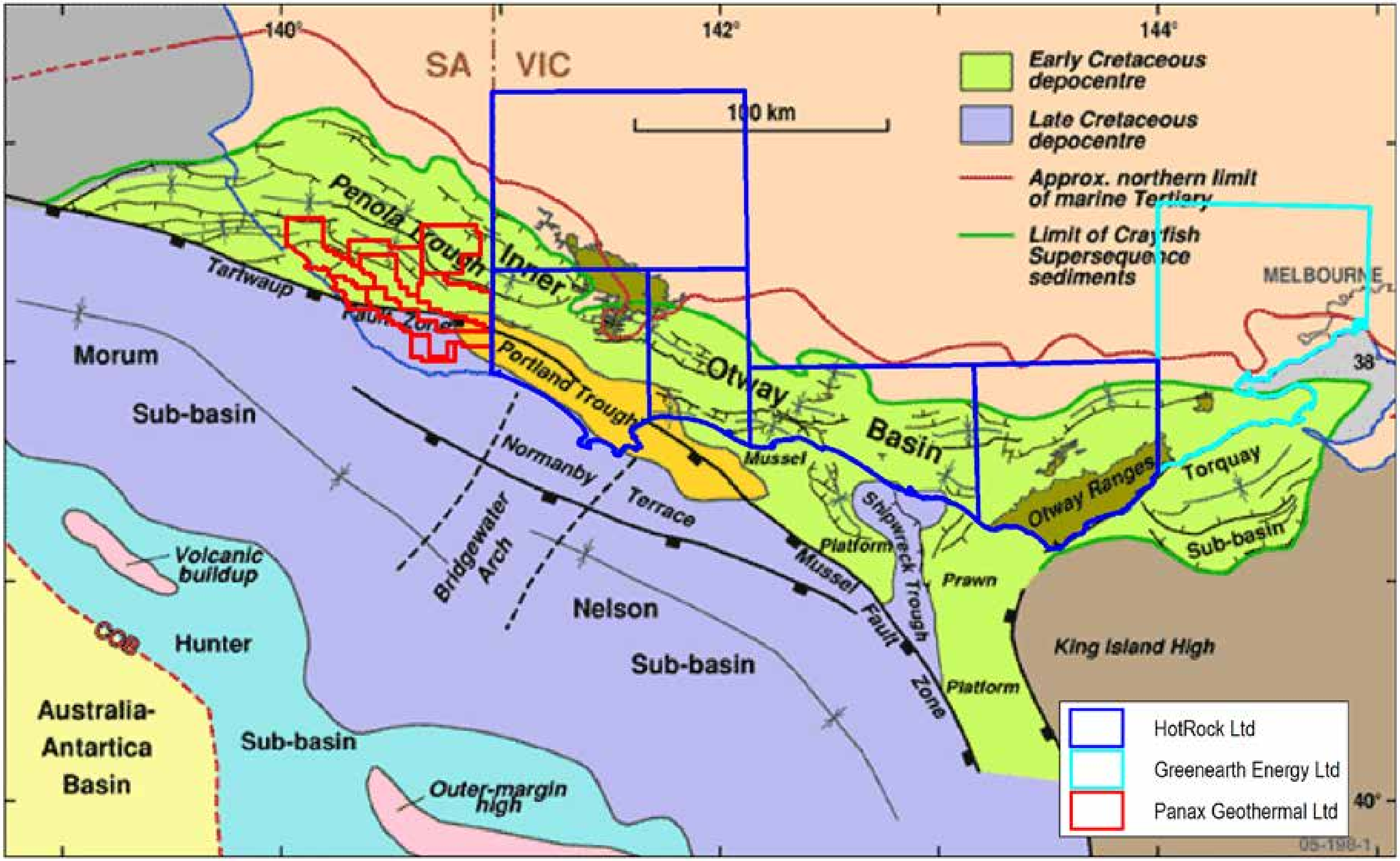
Geothermal setting of the Otway Basin (OB)

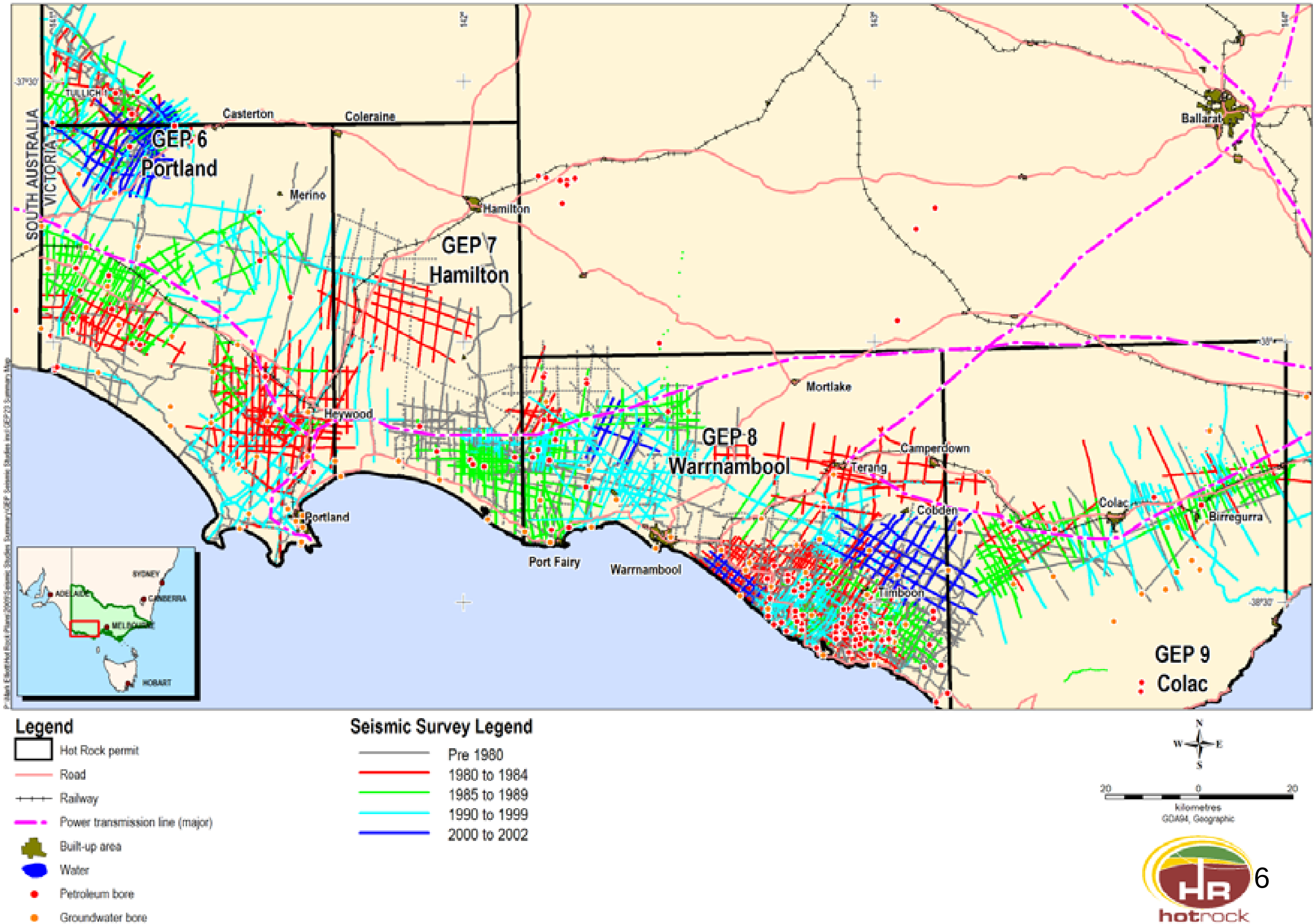


Base Graphic: Courtesy of Gescience Australia

Exploration of HSA Resources

- **HSA geothermal plays in the Otway Basin are blind – i.e. without observable discharge of heat or fluid at surface thus conventional geothermal exploration methods are less applicable.**
- **However, these resources can be well defined through use of extensive, readily available, regional geoscientific data sets, from particularly the petroleum and groundwater industries which include:**
  - seismic surveys
  - geological logs and temperature measurements from petroleum and deep water wells
  - other more recent geothermal specific surveys including Magneto Telluric (MT) resistivity surveys and well water geochemistry
- **Integrating these data sets, HRL has been able to delineate large HSA geothermal resources throughout the Otway Basin.**

Over 9,000 kms of seismic lines and 180 wells occur in tenements



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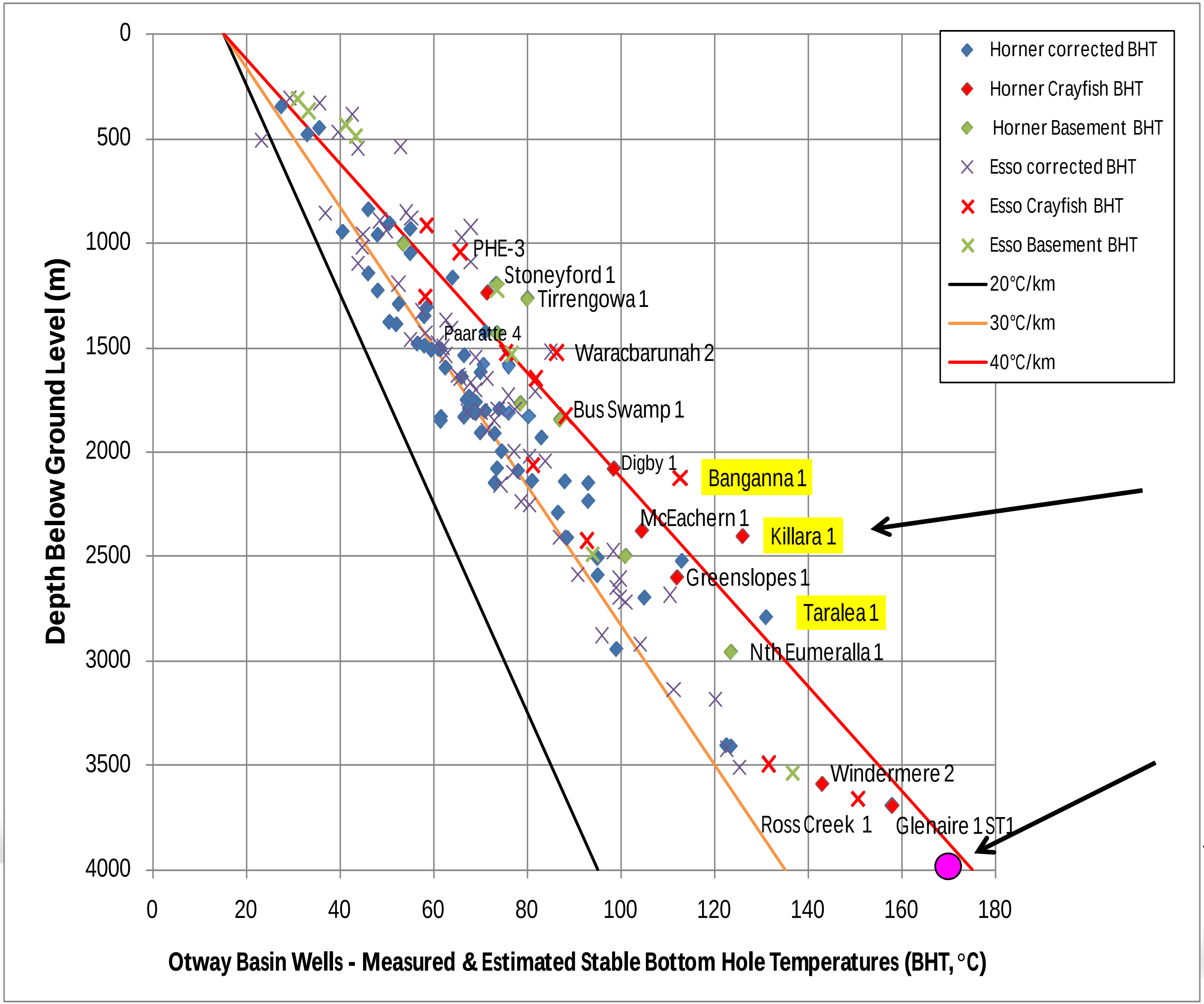
Extensive data base of measured and estimated stable formation temperatures (from 180 wells)

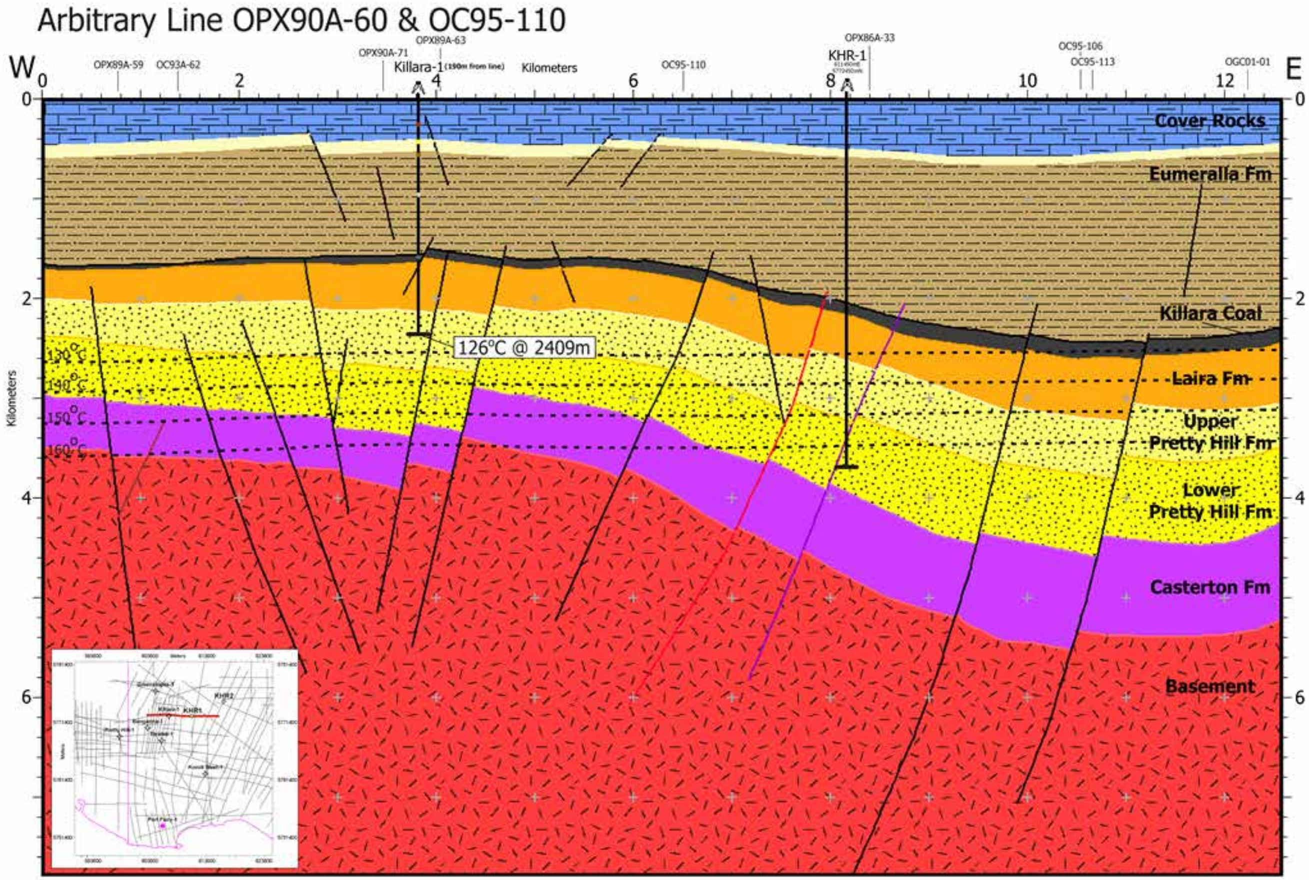


Highest geothermal gradients in the OB are at Koroit (from petroleum well temperature data)

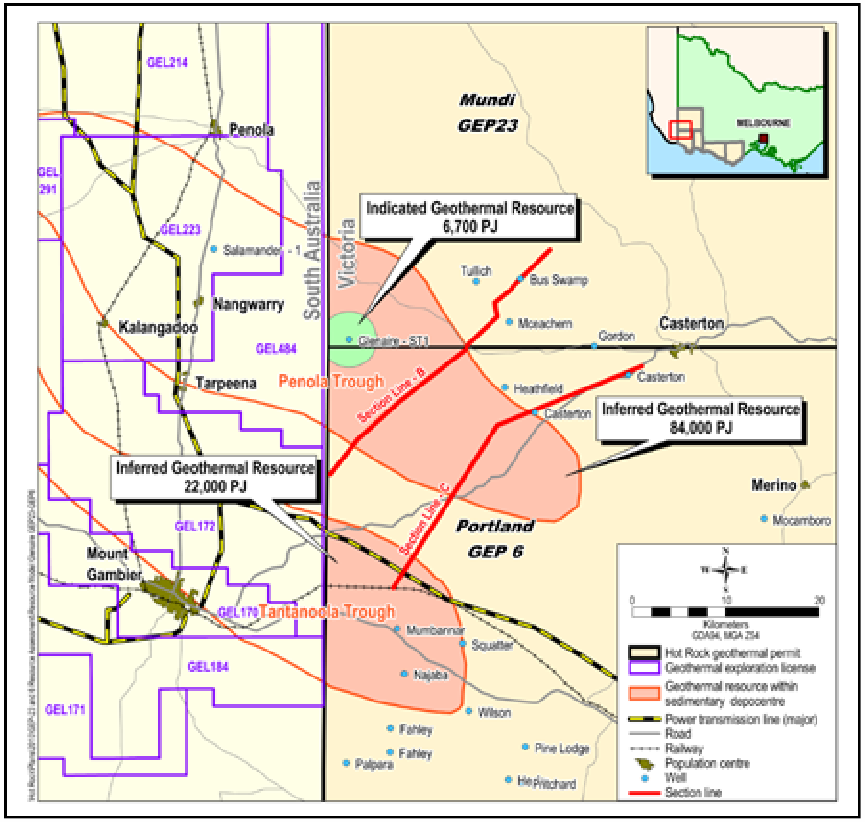
Maximum temperature In Panax well Salamander -1

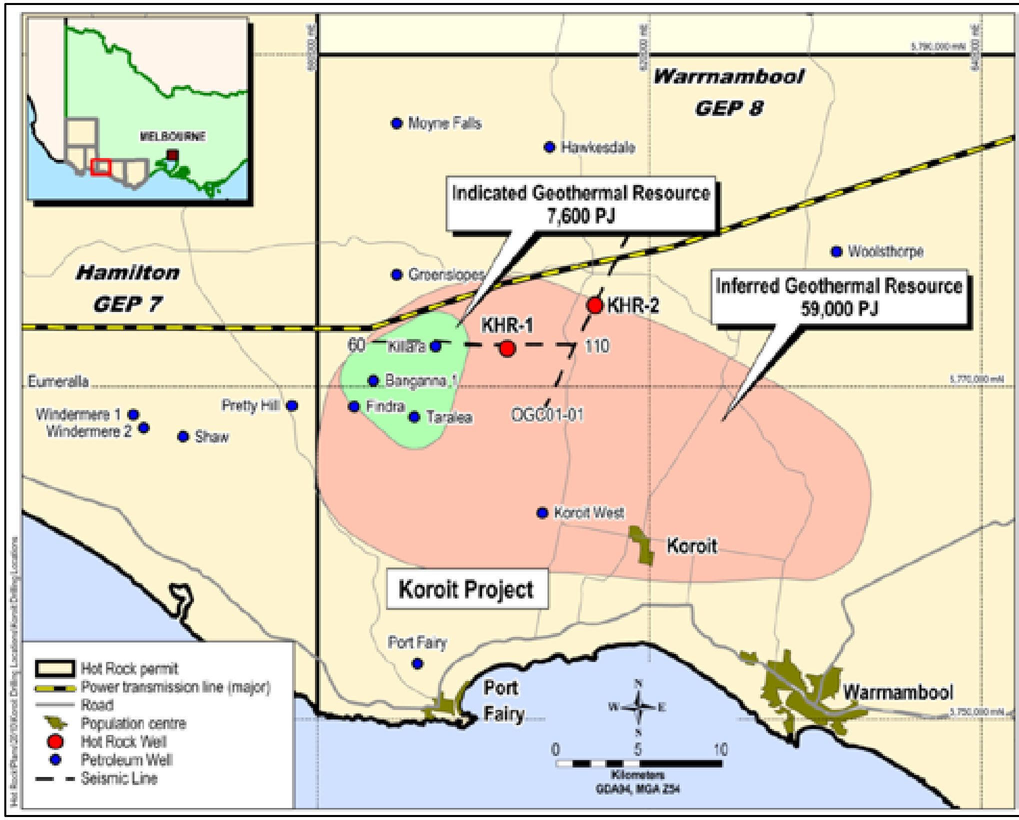
Integrated modelling of seismic and petroleum well geology and temperature data

- All available data has been integrated into detailed hydro-geology models - e.g. for the Koroit HSA geothermal resource
- These models incorporate stratigraphic and temperature data with detailed considerations on primary and secondary permeability



Geothermal resources delineated and declared in the Koroit, Penola & Tantanoola Troughs





HRL resource assessments declared in the OB

Resource	Tenements	Resource Area	Resource Volume	Estimated Resource Recovery Factor	P50 estimates of Recoverable Heat from			Estimated rate of electrical generation over 30 years
					Indicated Resource	Inferred Resource	Total Resource	
		km^2	km^3		PJ	PJ	PJ	MWe
Koroit	GEP-8	50	47	10%	760			140
Koroit	GEP-8	400	340	10%		5,900		1,100
Koroit	GEP-8	450	390		760	5,900	6,700	1,240
Penola	GEP-23	20	24	10%	500			40
Penola	GEP-23	120	150	10%		2,900		230
Penola	GEP-6	8	9	10%	170			10
Penola	GEP-6	290	306	10%		5,500		470
Penola	GEP-6 & 23	440	489		670	8,400	9,100	750
Tantanoola	GEP-6	180	130	5%		1,100	1,100	180
TOTALS		**1,070**	**1,010**		**1,430**	**15,400**	**16,900**	**2,170**

- These resource estimates are potentially recoverable heat and conform with the requirements specified in the "Australian Code for Reporting Geothermal Resource", 2nd Edition 2010
- More detailed information on these estimates refer to: http://www.hotrockltd.com/irm/Content/geothermal.html

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Power generation potential from HRL's declared geothermal resources

§ **17,000 PJ of potentially recoverable heat from HRL's HSA resources in the OB represents a very large natural store of energy , however, not all of this heat is available for conversion to electricity:**

- Only a small amount of the geothermal heat in these resources is potentially recoverable e.g. 5 to 10%
- Only a small amount of the heat recovered from the resources to surface will be converted to electricity in power plants due to thermal to mechanical energy losses e.g. 12%.
- The amount in-place heat that can be converted to electricity is typically: 10% (Rf) x 12% (Efficiency) = only 1.2% of the in-situ heat

§ On this basis of the 180,000 PJ of estimated in-place heat in HRL's OB tenements, only some 17,000 PJ is potentially recoverable heat which could generate some 2,000 PJ of electricity

§ Despite the apparent small size of this number 2,000 PJe is very large amount of electrical energy - equivalent to about 550,000GWh, equivalent in turn to more than 2,000 MWe of electricity generation for 30 years for a power plant with a capacity factor of 90%

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Risks in Otway Basin HSA

- HSA geothermal resources in the Otway Basin represent very large stores of natural heat energy – **a great start**
- Direct well temperature measurements in reservoir – **low risk**
- The key issue is how much of the heat can be recovered from these geothermal resources and this is dictated by well flow rate which is in turn is controlled by permeability of the reservoir rocks – **high risk**
- Permeability can be of two types:
  - Primary - associated with porosity
  - Secondary - associated with fracture and other structural permeability

And, permeability can be either:

- Naturally occurring, or
- Created through engineered processes:
  - chemical simulation to enhance existing porosity
  - mechanical stimulation through fracking to create new fractures or to enhance existing fractures

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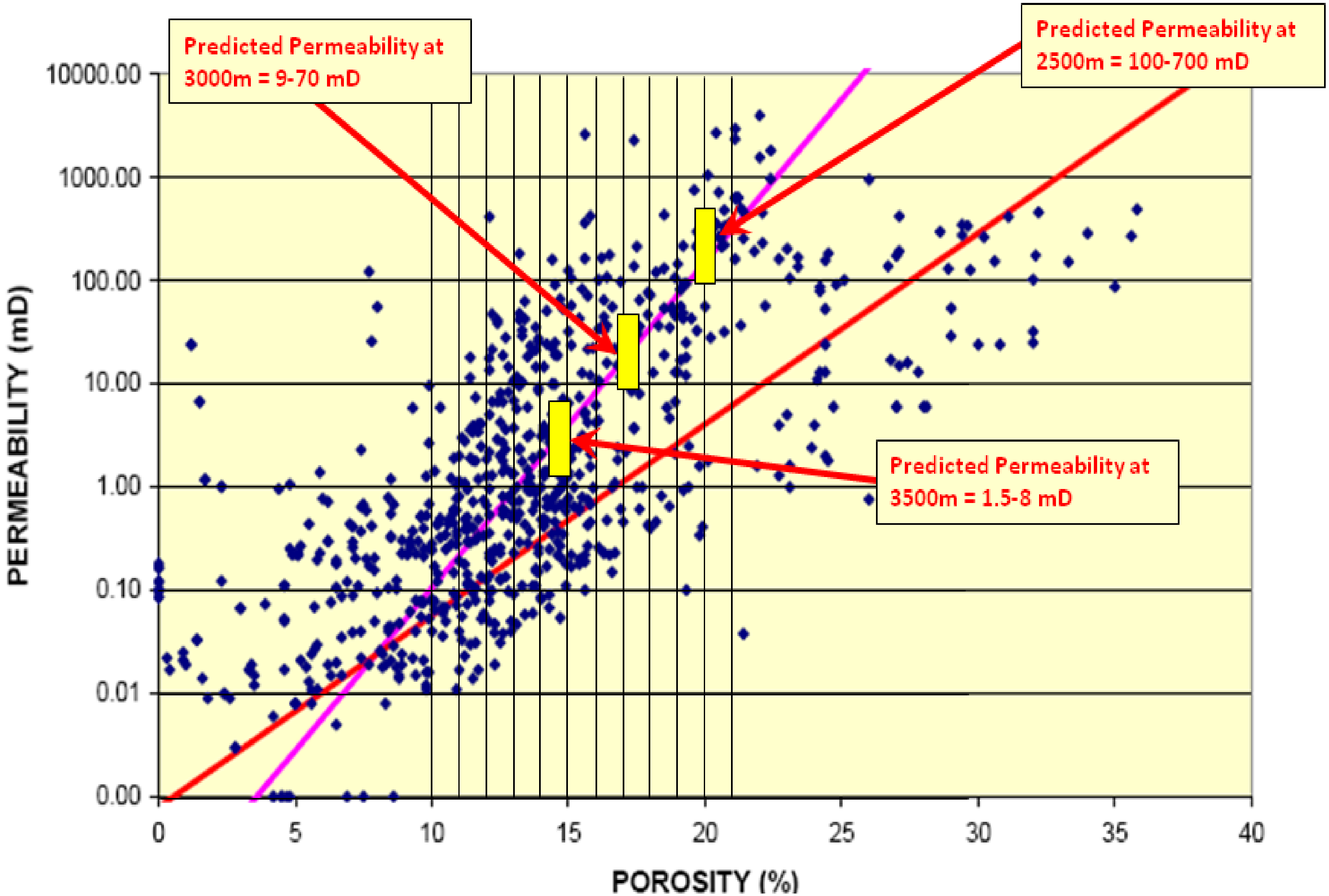
Estimates of primary permeability in OB

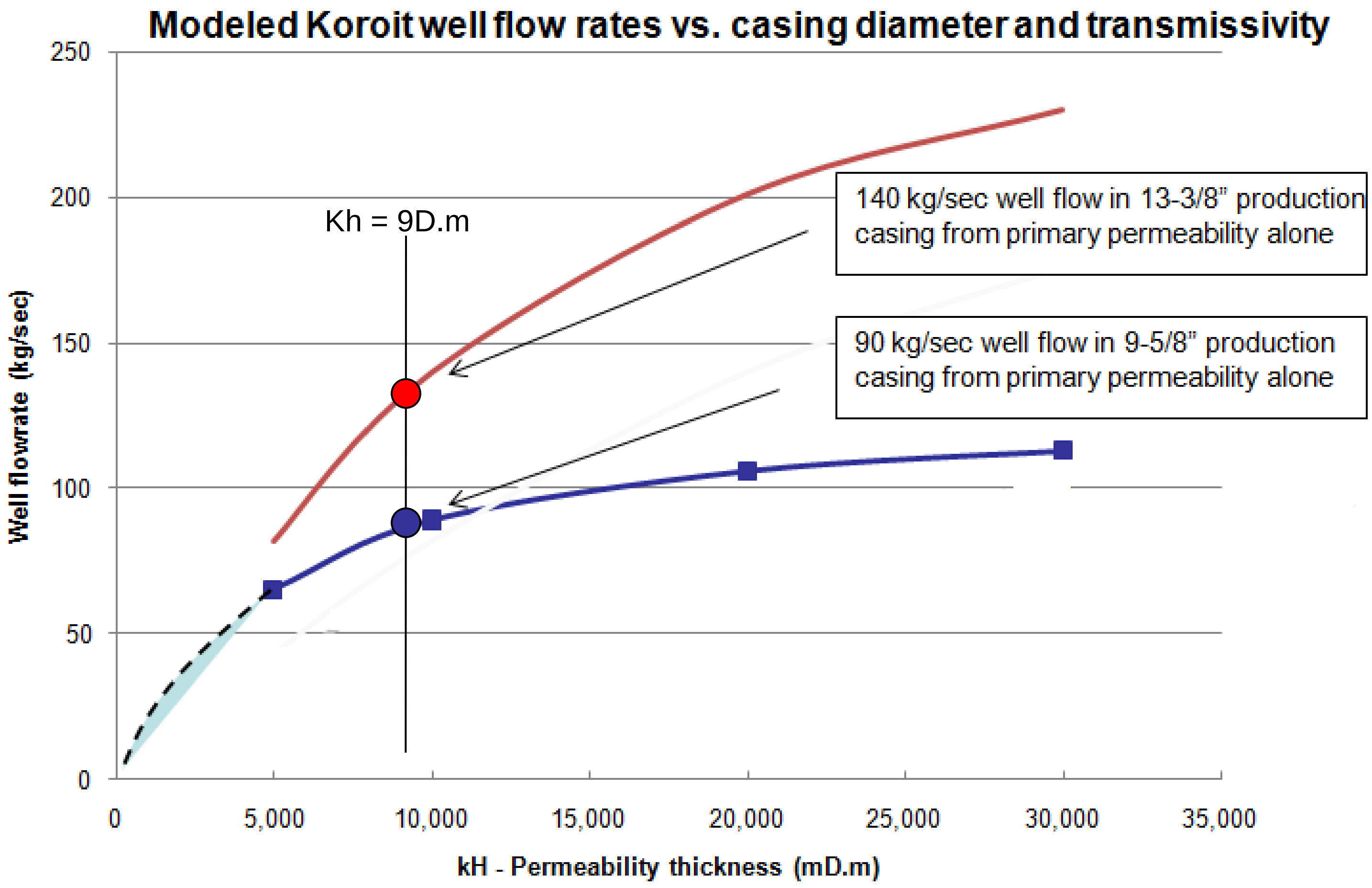


Estimates of primary permeability in OB

- The variation in poro-perm with depth in the figure above confirms:
  - porosity in the Pretty Hill Formation reduces with depth, from 20% at 2,500m to 14% at 3,500m, and
  - permeability decreases by two orders of magnitude between 2,500 and 3,500m.
- In spite of these reductions in poro-perm with depth, the evidence is that permeability within the Pretty Hill Formation at Koroit will still be sufficient to give commercial geothermal well flows from primary reservoir permeability alone.
- For example, for a conservative case using
  - the lower values in the range of the permeabilities predicted at each of the 3 depth ranges in the previous figure
  - a 500m production interval from 2600 to 3100m with a temperature range of 140 to 165^{o}C

  Then a transmissivity of 9 Dm results
- For this transmissivity value:
  - a standard size geothermal well completion (with a 9-5/8 inch diameter open production hole) can be expected to yield a flow rate of 90 kg/sec, and
  - a large diameter well completion (with 13-3/8 diameter production casing to yield a flow rate of 140 kg/sec from primary porosity alone (SKM, 2009) – see figure below.

Estimated Koroit well flow rates from primary permeability alone



Source: SKM (2009), Report prepared by Sinclair Knight Merz for Hot Rock Limited

Secondary permeability

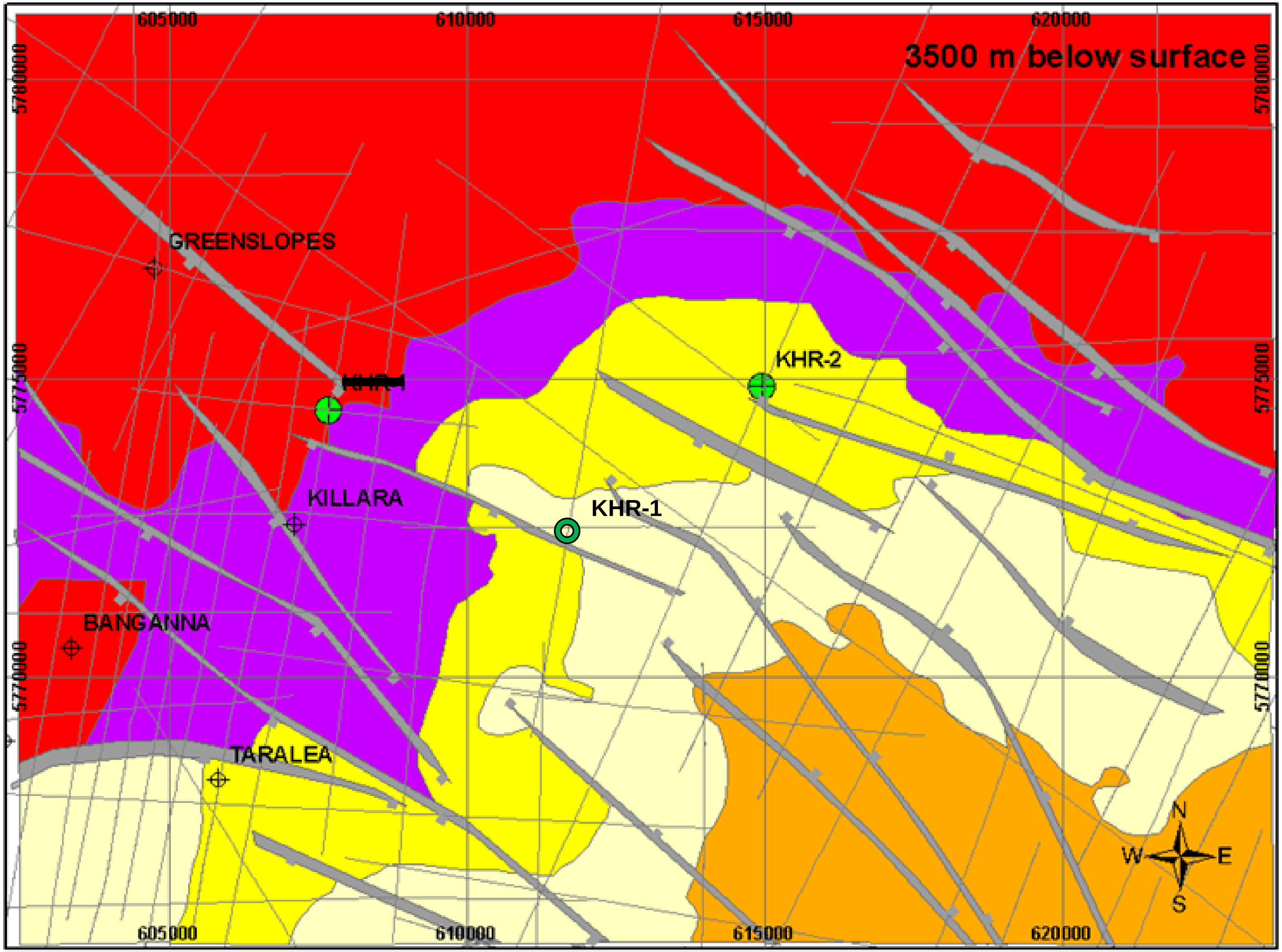
Few geothermal systems in the world, of any type, produce exclusively from primary permeability, even in HSA reservoirs, e.g.

- The Geysers, Wairakei and Ohaaki - conventional volcanic geothermal producing predominantly from fractures within very low porosity greywacke basement rocks
  - Production well flow from 30 to 140kg/sec are typical for standard size 9-5/8" production wells and 100 to 200 kg/sec for large diameter well completions with 13-3/8 inch production casings in conventional volcanic systems
- East Mesa and Heber HSA geothermal fields in the US – produce from a combination of fracture and primary permeability in fluviatile sandstones.
  - Heber is a very close analoque to Koroit with 7 standard size wells at the Heber II plant pumping 760 kg/sec of 165°C brine - an average of 110 kg/sec per well
- Germany – HSA geothermal production from fractured limestone.
  - Largest well tested to date is at Unterhaching with a pumped flow in a 9-5/8" production casing of 150 kg/sec of 122°C water from 3350m depth
- Turkey – A number of HSA resources within graben structural settings
  - A well at Aydin with a 7" production casing produces 111 kg/sec at 146°C

Assessment of secondary permeability in HSA resources in the Otway Basin

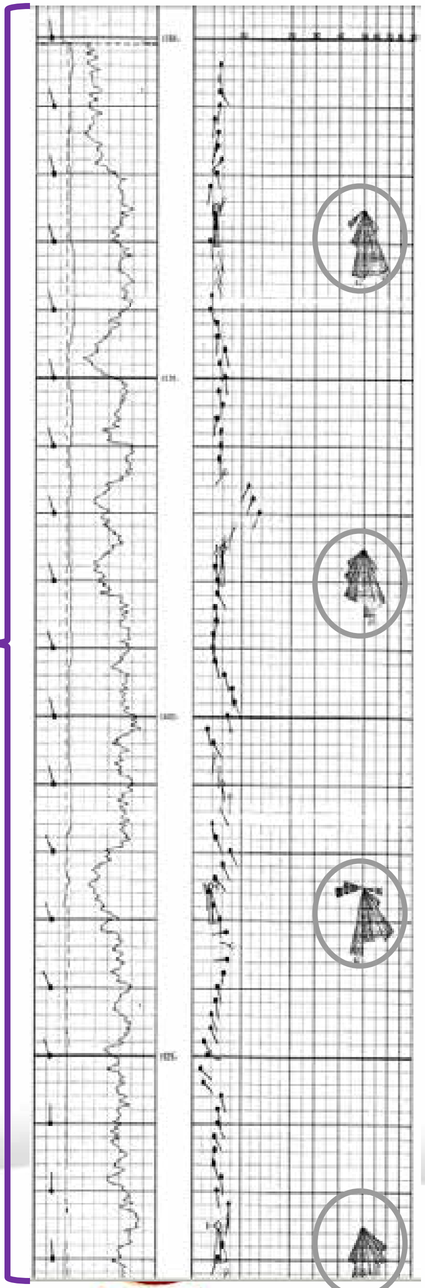
- There are well developed faults and structures in the Otway Basin at both large and small scale
- These affect both the Palaeozoic basement rocks and the overlying sedimentary successions, particularly the Crayfish Sub-group.
  - At large scale, analysis of structural geologic data for the Otway Basin has been interpreted to show:
    - faults and fractures orientated approximately WNW-ESE to NE-SW which are consistent with the present day stress regime, and
    - structures on these orientations are considered to be mechanically open, with good potential for providing secondary permeability channels for geothermal fluid flow.
  - At small scale, evidence for extensive fractures and faults in the Crayfish Subgroup within the Koroit resource, is evident in dip meter log data

Large scale evidence for faulting in the Koroit HSA geothermal resource (note the strong NNW trend for open faults)

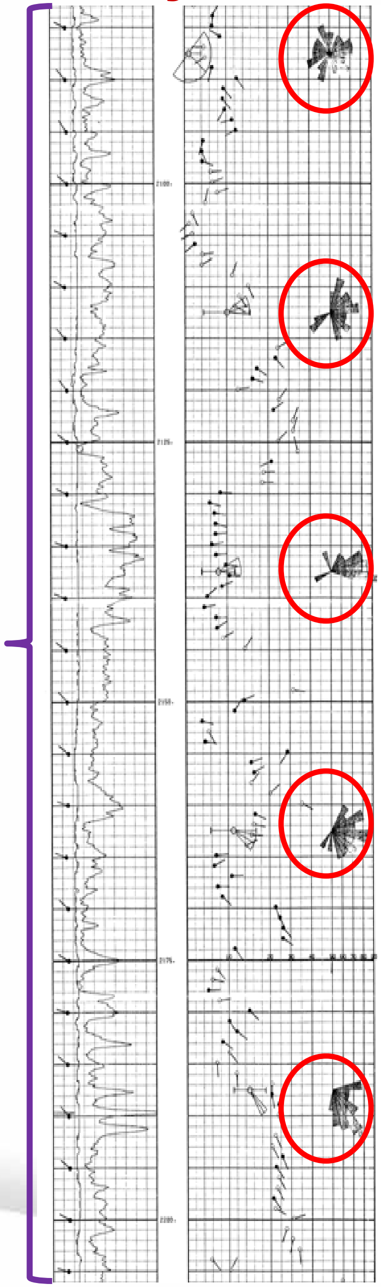


Phase 3 Scat Analysis – Killara Dip Meter

Eumeralla Formation



Pretty Hill Formation

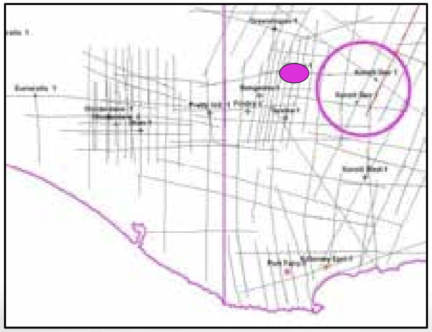


- Dip Meter measurements from the Killara-1 Well show a distinct change in dip pattern through the Pretty Hill Formation

- Dip azimuth measurements for Eumeralla Formation are typically consistent for the whole sequence.

- Dip azimuth measurements for the Pretty Hill Formation are inconsistent and highly variant

Pretty Hill Fm. has fault dips



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Summary of the Koroit geothermal resource

- In both HRL's estimation and confirmed by independent review, the Koroit resource represents the best HSA development prospect in the Otway Basin, having:
  - an areally extensive and thick sequence of Pretty Hill Formation (+1000m thick)
  - very good geothermal reservoir facies characteristics in the PHF (Clean sands)
  - the "right" temperature / depth for commercial exploitation (150^{o}C / 2500-3500m)
- The Pretty Hill Formation represents a very large store of geothermal heat with the potential to deliver from the Koroit resource alone in excess of 1000MWe and similar again from the Penola and Tantanoola HSA resources
- The key to development of the Otway Basin HSA resources is obtaining sufficient permeability:
  - There is good potential for primary permeability in the Pretty Hill Formation at relatively shallow depths (2500m to 3200m)
  - There is good potential for secondary (structural) permeability in the Pretty Hill Formation at deeper and hotter levels (3200 to 4000m)
- There are good indications that the combined transmissivity potential (from secondary plus primary permeability) may prove to be 15 Dm or better which would ensure commercial scale well flow rates (of >150kg/sec)

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Conclusions

- The Otway Basin and in particular, the Koroit Project has potential to generate significant clean, base-load geothermal electricity for Australia within 5 years of a discovery well being drilled.

- The average production temperature of around 150°C from 2500m to 3500m depth is estimated from direct temperature measurements in the Koroit reservoir from petroleum wells and is well suited for binary cycle power plant.

- Hot Rock believes that evidence for porosity and fracture permeability over parts of the Otway Basin is sufficient to provide high well flow rates (>150kg/sec).

- The key in moving the Koroit HSA project forward is to fund a test well to determine whether or not the flow rate from fractured and permeable sections of the Pretty Hill Formation reservoir is sufficient to provide for commercial scale electricity generation.

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Tower Hill, a large 'maar' crater within the Koroit HSA geothermal project