Salamander-1 – a geothermal well based on petroleum exploration results

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Salamander-1 and the Penola Geothermal Project

Panax Geothermal Ltd ("Panax") has secured several Geothermal Exploration Licences (GELs), within troughs or grabens in the Otway Basin in southeast South Australia (Fig 1). Together the licences cover an area of more than 3,000 km^2. The initial development of the Limestone Coast Geothermal Project is focused on the Penola Trough (GEL 223 and GEL 484; Fig. 2) - promoted by an existing comprehensive database of historical informaton from extensive oil and gas exploration and production.

The Penola Trough has been subjected to intensive oil and gas exploration, including 27 deep petroleum wells with wireline logging and conventional core measurements of reservoir porosity and permeability. In addition, 321 km^2 of 3D seismic and a significant amount of 2D seismic data have been acquired in this area. All of this data is available as part of a public open file database.

Geological setting

The Penola Geothermal Project lies within the Penola Trough, which is a Cretaceous-aged extensional basin formed on top of Palaeozoic basement. It is covered in South Australia by GEL 223 and GEL 484. The Penola Trough forms part of the Otway Basin, a rift basin initiated during the Cretaceous, on what is now the southern margin of the Australian mainland. The trough contains a thick accumulation of Cretaceous sediments and is bounded to the northeast by the Padthaway Ridge, and to the southwest by the Kalangadoo High. Well and seismic data indicate that the sediment pile is six kilometres thick or more, in the deepest sections of the trough, including over 1,000m thick sections of cretaceous Pretty Hill Formation (sandstones).

The Penola Trough area of the Limestone Coast Project bears many similarities with the Imperial Valley area of California which includes the East Mesa and Heber geothermal areas (Bergosh et al., 1982). The East Mesa reservoir sandstones are similar to the Pretty Hill Formation sandstone, which is the target reservoir of the propsed Hot Sedimentary Aquifer (HSA) system of the Limestone Coast Geothermal Project.

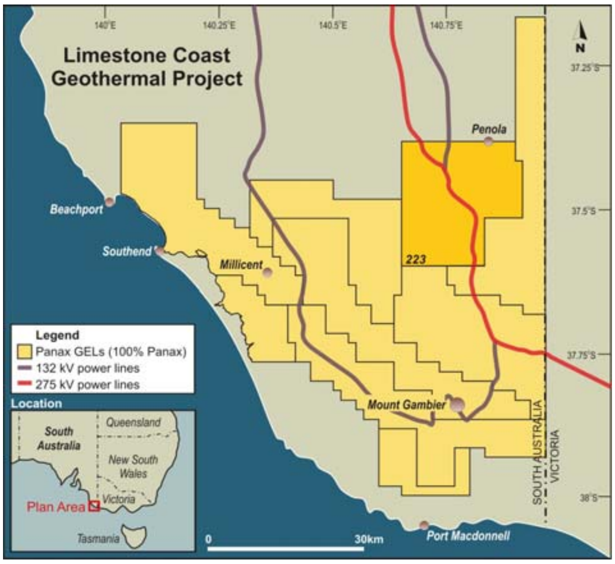


Figure 1. Panax's geothermal licences in the Limestone Coast Geothermal Project – demonstrating proximity to infrastructure

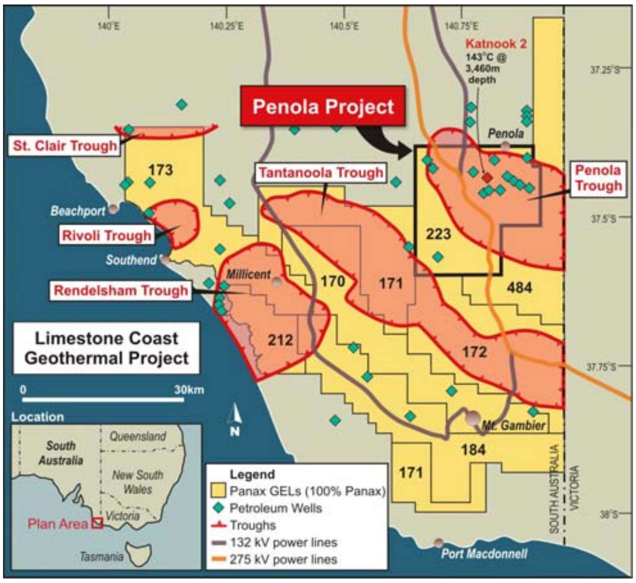


Figure 2. Panax's geothermal licences in the Limestone Coast Geothermal Project – outlining four major trough zones, including the Penola Trough and the Penola Geothermal Project

The Pretty Hill Sandstone was deposited by a low sinuosity, high energy, sand-rich river system (Scholefield et al, 1996). Its good reservoir quality has been known from petroleum activities for some time. Significant permeability is preserved in the formation at depths of up to 3,500m.

3D seismic data has been particularly useful in mapping the distribution of the porous sandstones of the Pretty Hill Formation. The seismic response evident on 3D data represents to some extent the porosity distribution within the Pretty Hill Formation (Boult & Donley, 2001). The lower acoustic impedance of the more porous sandstones can be identified on the basis of the data (with varying degrees of success), and has been used to map the distribution of individual sandstone bodies.

Temperature data, and rationale for Salamander-1

A numerical model was generated for the Penola Trough to compute, in three dimensions, the distribution of temperature which best matches the observed surface heat flow distribution, while respecting the laws of conductive heat transfer, and the thermal properties of the geological strata. The model predicted that the temperature is relatively constant around 160°C at 4,000 m within most of the Penola Trough. This temperature modeling and a knowledge of the reservoir quality provided the rationale for the drilling of the first geothermal well, Salamander-1, in the Penola Trough in the first quarter of 2010.

Additionally, Beardsmore (2009), assessed the Limestone Coast Geothermal Project for its geothermal potential and determined a “Measured Geothermal Resource” of 11,000PJ complemented by an additional 32,000 PJ of “Indicated Geothermal Resource”, see Table 1 below. This resource classification was in accordance with the Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves, 2008 edition.

This highly encouraging resource classification, the third in Australia and second-ever resource classification of a HSA, confirmed the high potential of geothermal energy development in sedimentary basins.

The ability to directly assess this significant geothermal resource potential is courtesy of the long history of petroleum exploration with numerous wells and seismic surveys, see figure 3 below.

Limestone Coast Geothermal Resources [1.]					
Trough	Measured (PJ)	Indicated (PJ)	Inferred (PJ)	Total (PJ)	Report Date
Penola	11,000	32,000	89,000	132,000	18/02/2009
Rivoli & St. Clair			53,000	53,000	28/01/2009
Rendelsham			17,000	17,000	28/01/2009
Tantanoola			130,000	130,000	31/03/2009
Total	11,000	32,000	289,000	332,000	

Table 1 - Reproduced from the 2008 Penola Trough Report by Dr. Graeme Beardsmore (Hot Dry Rocks Pty Ltd)

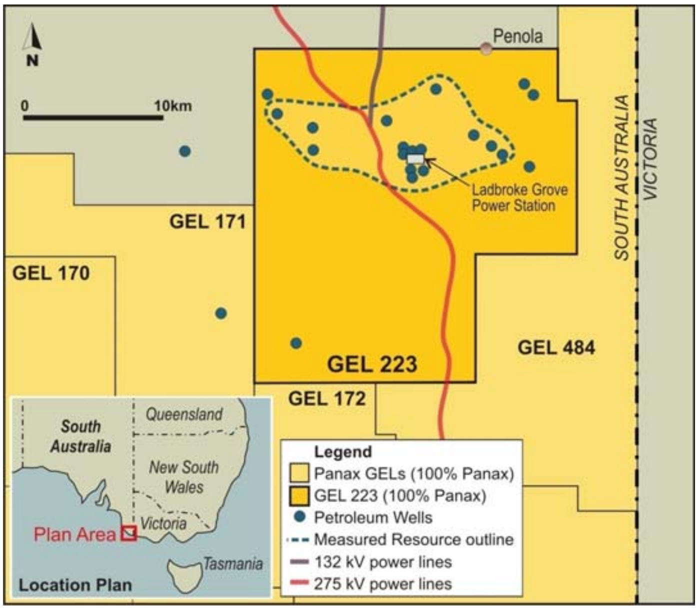


Figure 3. GEL 223 – Penola Geothermal Project showing outline of the Measured Geothermal Resource, and information relating to prior petroleum wells drilled in the area.

Salamander-1 drilling objectives

Salamander-1 is the first geothermal well in the project area. It was drilled in Panax’s Geothermal Exploration Licence 223 (GEL223), in the first quarter of 2010.

The drilling objective for Salamander 1 was to intersect the Pretty Hill Formation (reservoir) at a depth of 3,000m and continue to 4,000m to secure an intersection of 1,000m of the reservoir. To minimise the risk of intersecting gas, the well was sited 5km away from the closest gas producing well (now depleted) and at least 500m vertically down dip of any gas producing well. Also, a further drilling requirement was that no significant faults should exist between the closest gas producing well, and Salamander 1 - that could potentially be a gas seal.

To minimise friction losses in a future production environment, the casing scheme was designed as wide as possible, although standard casing dimensions and safety issues took precedence. Figure 4 below presents the casing scheme for Salamander 1.

Drilling

Salamander was drilled with Weatherford's Rig 828 and the design and management of the well was contracted to AGR.

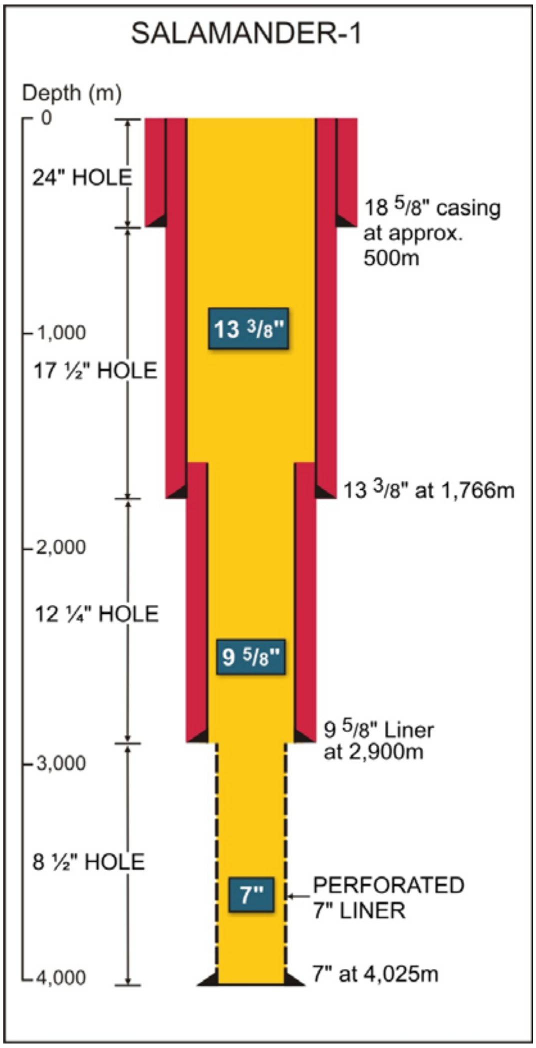


Figure 4. Schematic illustration of the well design and well casing design – Salamander-1

WDI Rig 828 was handed over to Panax at the rig's previous engagement at 20:00 on 12 December, 2009. The rig move to Salamander 1 was disrupted due to poor weather restricting truck access to the rig, in particular the larger transporters. Salamander-1 was spudded at 23:45 on 31 January 2010.

The 24" hole was drilled from the base of the 26" conductor to 503m, and 18-5/8" casing was run and cemented at 499m (Figure 4).

The 17-1/2" hole was drilled from the 24" casing shoe to 1,766m. Due to lower Rates of Penetration (ROP), Panax elected to set 13-3/8" casing at this depth. The 13-3/8" casing was run and cemented at 1764m.

The 12 ¼" hole was drilled using Schlumberger's Power V system, an auto-vertical seeking directional drilling tool, to maintain verticality. The ROP in the 12-1/4" section was extremely good and intersected the top of Pretty Hill Formation at 2,900m, some 150m shallower than the original prognosis.

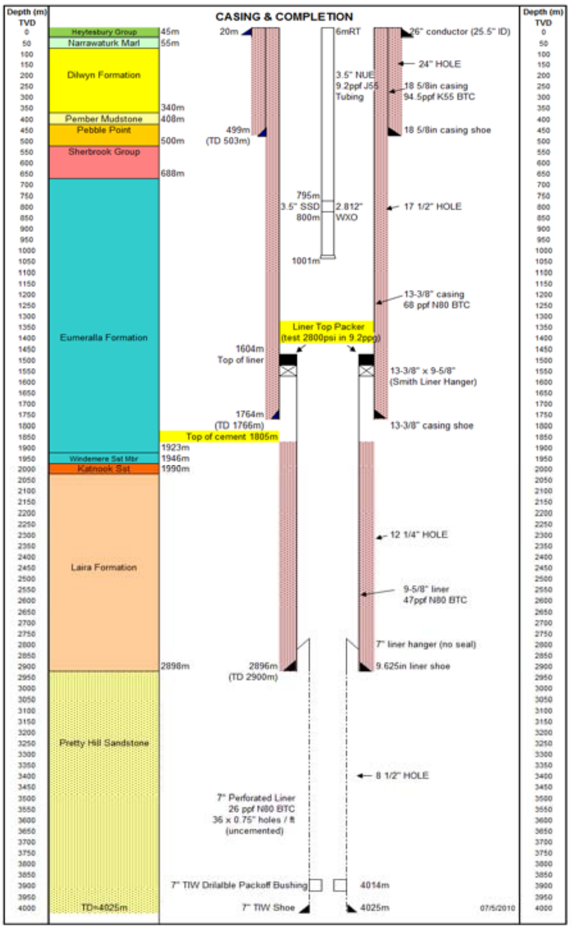


Figure 5. Salamander-1 Well Completion Schematic

A cement plug was set from 2,800 – 2,900m to stabilise this zone, and the 9 5/8" liner was run and cemented at 2,896m.

The 8-1/2" hole section was drilled to 4,025m with a bit change made at 3,670m. An EMS directional survey was recorded at TD and Open Hole logs were run. A 7" perforated liner was run and set to bottom.

Following displacement of the drilling fluid with brine, and with the wellhead and Christmas tree installed, the rig was released at 1500 hrs 26 March, 2010.

The well was drilled to a total depth of 4,025 metres in 45 days (inclusive of 3 rig repair days) using only 6 drilling bits, setting a new drilling record for the Australian geothermal sector.

Importantly, the Salamander-1 drilling programme was concluded with zero Lost Time Incidents

Wireline logging

The wire-line logging services were provided by Schlumberger, and four trips were planned. The main objectives of the wire-line logging were to: i) determine formation acoustic velocities to tie in the well with 3D surveys, ii) observe pressure regimes to determine the absence of any hydrocarbons, and iii) collect information about formation density and porosity. The wire-line programme is presented in Table 2 below.

Log	Interval
XY Cal-GR	2890 – 1750m
DLL MSFL LDT CNL-GR	4021.5 – 2898m
HNGS	3738 – 2898
Sonic Scanner	4025 – 2989
	2900 – surface. Sonic scanner switch modes to Cement Bond Log
MDT-GR	37 points (could not pass 3845m)
VSI-4	3810 to 99m

Table 2 – Wireline Logs Obtained

Salamander-1 Well Results

The recently announced 15.4°C increase in the measured bottom hole temperature ("BHT") of the Salamander-1 well, from 156°C to 171.4°C, which is likely to have been caused by breakthrough from the well bore to the reservoir, has confirmed predictions of the regional 3D temperature modelling by Hot Dry Rocks Pty Ltd (HDR Report, 2008). Figure 6 below shows that the 3D modelled temperature at 4,025m for the Salamander-1 well of 172°C is very close to the recently measured BHT at 4,000m of 171.4°C. This figure also shows that projected temperatures at 4,000m increase to the south and south-east into Panax's GEL484, reaching 180°C within 4km of Salamander-1.

The new BHT of Salamander-1 combined with the new 3D temperature modelling is likely to increase the geothermal resources of GEL223. More importantly, it upgrades the overall regional potential of the Penola Geothermal Project, with higher temperatures allowing the proposed power outputs to be achieved with lower flow rates.

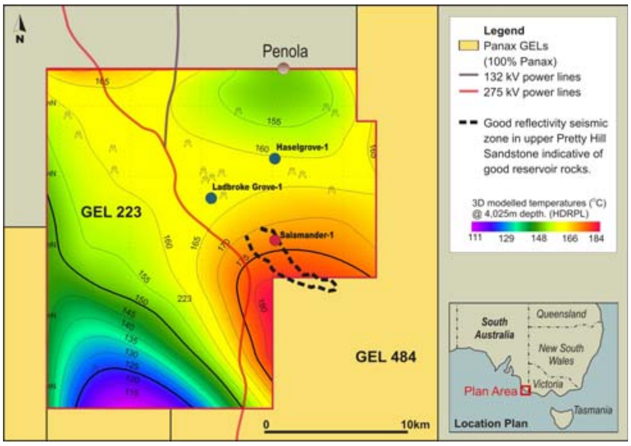


Figure 6 - Penola Trough, 3D conductive heat flow modelling (HDR, 2008) - predicted 172°C @ 4,025m, while the actual measured temperature at Salamander-1 for this depth was 171.4°C – recently measured.

A borehole seismic survey (vertical seismic profile or VSP) was recorded by Schlumberger in the near vertical Salamander-1, on 19 March 2010. This VSP allowed a good correlation of the Salamander-1 penetrated geology with the 3D seismic data. Examination of the seismic data correlated to Salamander-1 located towards the southeast of the GEL, shows an excellent correlation, with a more reflective seismic package in the upper section of the Pretty Hill Formation. Seismic attributes of reflection strength, and volume attributes of RMS reflection strength were used to determine the areal distribution of these more porous sandstones. A single reservoir body is interpreted extending from the Ladbroke Grove gasfield area, through the Salamander-1 well, and 6.5km to the south east - covering an area of approximately 22.5km^2. This zone is interpreted as having similar reservoir properties to those in the well.

Full analysis of the petrophysical review are currently in progress and will be available at the time that the paper is presented in November 2010.

A review of the wireline logging data of the open hole section of the Salamander-1 well (from 2,900m to 4,025m) for estimating the reservoir quality of the target reservoir rocks (the Pretty Hill Sandstone) has been completed by Down Under Geosolutions ("DUGEO") based in Perth. We have been advised that the combination of the "Lin-Log and MDT methods" are the most appropriate to estimate the "transmissivities" (≈

reservoir quality) of the intersected target reservoir rocks.

DUGEO has advised that the transmissivities in Darcy metres (Dm) of the Pretty Hill Sandstone in the open hole section of Salamander-1 well range from 6.7 Dm to 13.5 Dm, as set out in Table 3 below:

	Method	Transmissivity (Dm)
Most Likely Case	Average Lin-Log relationship	6.7
Maximum Case	Optimistic Lin-Log relationship	13.5

Table 3. Transmissivity Range

Transmissivity is loosely described as the capacity of the reservoir to flow water. The "Most Likely Case" of 6.7 Dm is lower than the minimum requirements of 10 Dm for a flow rate of 175 l/sec @ 145°C. However, with higher geothermal temperatures now apparent (from the most BHT measurement in Salamander-1, and consistent with the 3D temperature modelling), flow rates could be reduced as these two inputs are inversely proportional. Also, the "Maximum Case" estimate provides the upside.

Salamander-1 Well Testing

Salamander-1 was discharged using air lift to a 10,000m^3 capacity HDPE lined pond. Steam was vented to atmosphere from a flash tank and water flow was measured using a weir plate.

The reservoir fluids collected in the pond will be used for the injection test which is the last test to be carried out on the well.

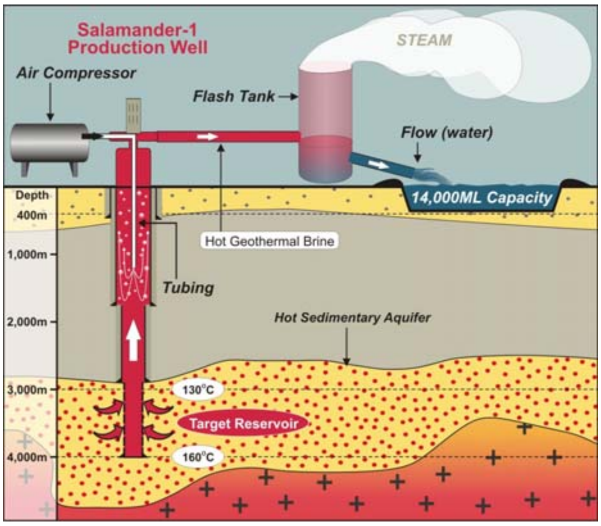
Analysis of downhole pressure and temperature data obtained during short cleanup flows, although indicating higher than expected temperatures, up to 171 deg C also indicated initial mud damage that arose during drilling.

The well was acidized using 15% acetic acid in order to remove the skin damage caused by calcium carbonate and flowed again using nitrogen gas lift. Results of this operation are awaited.

Results of production and injection testing are pending. Based on the results of these tests, the feasibility of installing a pilot plant will be investigated.

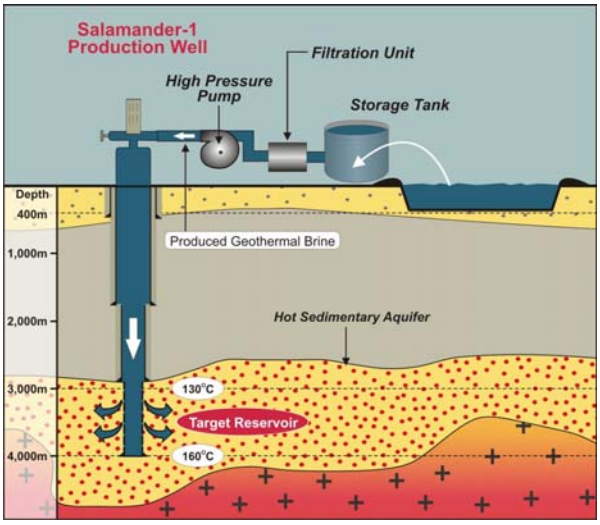
A number of depleted gas wells within approximately a 5km radius of Salamander-1 were checked for injection potential. It is estimated that 4 of these wells could accept more than 100 l/s in their current configuration and more than 200 l/s after workover, with further improvement possible with additional perforation. The costs of working over these wells are in the range $2-3m each, which is a much more economic proposition than drilling a purpose built reinjection well.

Salamander-1 Reservoir Testing Program – Step 1 :



a. Flow well using air lift;
b. Measure pressure, temperature and flow (surface), down hole logging tools in the target reservoir measure pressure, temperature and flow.

Salamander-1 Reservoir Testing Program – Step 2 :



c. Re-inject produced geothermal brine using filtration unit and high pressure pump;
d. Down hole logging tools in the target reservoir measure pressure, temperature and flow.

Figure 7. Salamander-1 Well clean-up flow test, May 2010.

Salamander-1 – Interpretation And Analysis Of Well Testing Results

At the time of writing this Abtract, this work is currently being undertaken.

This will be available for presentation at the time that the paper is presented in November 2010.

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